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The Cylindrical Component Methodology Evaluation Module for MUVES-S2

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NOTICES

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Survivability/Lethality Analysis Directorate, ARL

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14. ABSTRACT

The US Army Research Laboratory’s Survivability/Lethality Analysis Directorate Aviation Team has developed an evaluation module (EM) for MUVES-S2 for computing the probability of component damage given a hit ($p_{cd/h}$) for ballistic threats versus cylindrical components. The EM is called the Cylindrical Component Methodology (CCM). The methodology is based on a fraction of circumference removal kill criterion and is applicable to both hollow and solid cylindrical components (e.g., control tubes, drive shafts). The EM directly computes the $p_{cd/h}$ for each encounter, eliminating the need to use predetermined $p_{cd/h}$ tables for these component types. The CCM EM was integrated into the latest version of MUVES-S2 in fiscal year 2016.

15. SUBJECT TERMS

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1. Introduction

This report documents the development of an evaluation module (EM) for MUVES-S2 for computing the probability of component damage given a hit ($p_{cd/h}$) for ballistic threats versus cylindrical components. The EM is called the Cylindrical Component Methodology (CCM). The methodology is based on a fraction of circumference removal kill criterion and is applicable to both hollow and solid cylindrical components (e.g., control tubes, drive shafts). The EM directly computes the $p_{cd/h}$ for each encounter, eliminating the need to use predetermined $p_{cd/h}$ tables for these component types.

2. Background Information

The Survivability/Lethality Analysis Directorate (SLAD) Aviation Team currently uses $p_{cd/h}$ tables for cylindrical components that are based on cylindrical component methodology originally developed in the 2009–2012 timeframe. This version of the methodology was a spreadsheet-based program, which computed $p_{cd/h}$ values using the percentage of component circumference removed by a given threat diameter, regardless of penetration. These "baseline" $p_{cd/h}$ values were then adjusted for penetration based on threat velocity. The methodology evaluated 2 types of damage: single-aperture slicing shots near the component edge (C-shot) and double-hole shots through the middle (2X-shot). These 2 damage types were combined to get a single probability of kill. Additionally, the methodology considered threat hole diameter growth due to impact with the component and nonaligned shots due to yaw. Documentation of this methodology is provided in a separate technical report.[1]

In 2014, the SLAD Methodology Team updated the cylindrical component methodology, producing a stand-alone version written in C++. The new methodology was still based on percentage of circumference removed (Cr) but differed somewhat from the original version. First, the original version only considered the direct hit condition, which occurs when the center of the threat projectile impacts the target. The new methodology expanded on this to include impacts due to the entire diameter of the threat projectile. This approach, referred to as effective size, was accomplished by defining an effective component diameter, which is the actual component diameter plus the diameter of the threat. Second, the new methodology did not consider the effects of threat hole size growth and yaw.

Initial comparisons of $p_{cd/h}$ computations between the old and new methodologies yielded significant differences. Comparisons improved when the effects of hole size growth and yaw were taken into account. However, using an effective component diameter for the newer methodology still resulted in consistently lower $p_{cd/h}$ values when compared with the original. Subsequently, an update to the new methodology was developed to allow computation of direct hit $p_{cd/h}$ also. The CCM EM is based on this latest methodology.

3. CCM EM Description

A detailed derivation of the CCM EM is provided in Appendix A. The initial algorithm is for the effective component diameter condition, which considers a strike to occur as soon as any portion of the threat impacts the component. To do so, the diameter of the threat is added to the component diameter to arrive at the effective component diameter. Two cases are examined: a threat diameter greater than the component diameter and a threat diameter less than the component diameter. Expressions for $p_{cd/h}$ are derived for each case based on component and threat geometries and the circumference removal criteria. The $p_{cd/h}$ computed is based on a random hit on the component: both C-shot and 2X-shot damage types are taken into consideration. Appendix A also includes modifications made to the methodology to account for the direct hit condition.

The CCM EM is treated like any other evaluation module in MUVES. Components are assigned to it in a similar manner. Two methodology options are available: effective size and direct hit. For the effective size methodology, changes to certain attributes must also be made in the BRL-CAD target description file for the applicable components. Either methodology requires a cylindrical kill criteria value, which is the fraction of Cr resulting in failure. Sample criteria for some common cylindrical components are given in Table 1.

Table 1 Sample fraction of Cr criteria

Component type	Material	Dia. (inches)	Cr
Thin-walled control tubes	Aluminum	0.5	0.30
		0.75	0.40
		1.0	0.45
		1.25	0.47
		1.5	0.48
		1.75	0.51
		2.0	0.54
Main rotor output shaft	Steel	1.5	0.30
Tail rotor output shaft	Steel	2.4	0.35

Another option available is threat hole growth, which is expressed as a percentage increase of the threat diameter. A threat often leaves a slightly larger hole than its actual diameter after penetration due to petaling effects of the component metal and other factors. Finally, an option is available to set the maximum incidence angle, which is measured between the shot line and the longitudinal axis of the component (0° = perpendicular, 90° = tangential). This option allows one to only consider damage within a certain portion of the component length. The reason for this is that the circumference removal criteria only apply to localized damage (e.g., 2 holes located at opposite ends of the component are not equivalent to a 2-hole shot aligned perpendicularly to the component axis).

The CCM EM has been tested for the following threat types: armor piercing (AP), armor-piercing incendiary (API), kinetic energy (KE), shaped charge jet (SCJ), explosively formed penetrator (EFP), and fragments. For the high-explosive incendiary (HEI) threats, each fragment that hits the component is evaluated and the total are survivor summed to compute the final $p_{cd/h}$. Detailed test case results are provided in Appendix B. For verification purposes, manual $p_{cd/h}$ calculations were made and compared to results from the CCM EM. A description of the manual calculations along with an example follow in Section 4.

4. Manual Calculation

This section demonstrates a manual evaluation of the CCM methodology for a 1-inch-diameter tube, a 0.5-inch threat diameter, and a 40% failure criteria. The 40% failure criteria results in 144° of the tube's circumference being removed to cause a failure. Figure 1 shows the projectile just grazing the top of the tube. The orange region defines the amount of tube circumference required to be removed to fail the tube. As shown in Fig. 1, at a height of 0.000 inches, the threat does not remove a sufficient amount of the tube's circumference to meet the failure criteria.

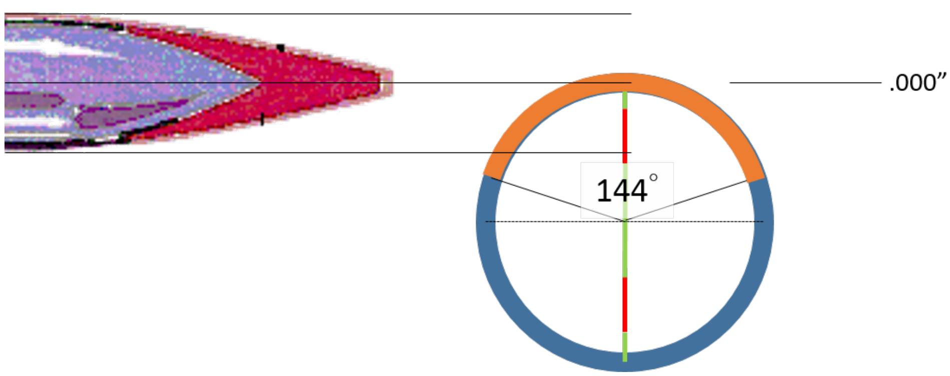

Fig. 1 Threat impact at 0.000-inch shot line height

The minimum shot line height, Fig. 2, required to achieve the 40% failure criteria is calculated in Eq. 1. The 72° angle is one half of the 144° failure criteria.

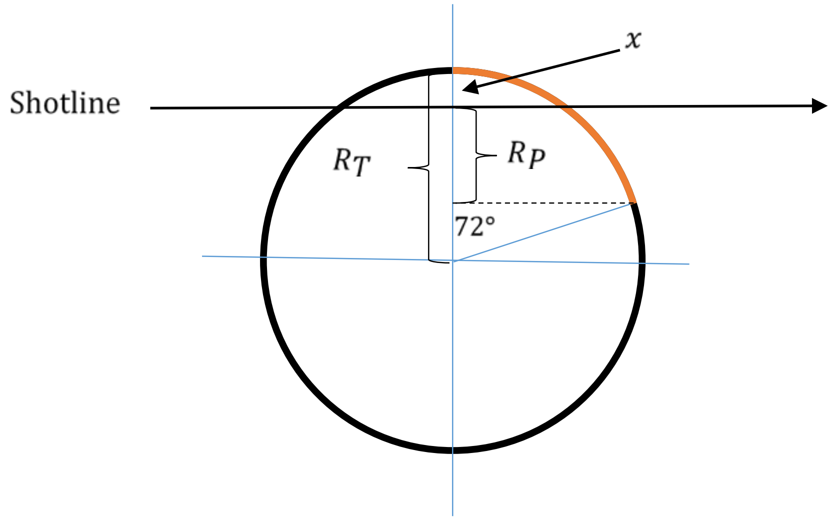

Fig. 2 Minimum shot line height

R_T = Tube Radius (0.5 inch)

R_p = Projectile Radius (0.25 inch)

x = Shot Line Height

$$\cos 72° = \frac{R_T - (x + Rp)}{R_T} \tag{1}$$

$$\cos 72° = \frac{0.5 - (x + 0.25)}{0.5}$$

$$x = 0.096"$$

For this example, the projectile diameter is equal to the tube radius. Therefore at a shot line height of 0.25 inch, the projectile will remove 50% of the tube's circumference. Shot line heights greater than 0.25 inch will result in a double-aperture hole rather than a slicing shot. A double-aperture hole can still achieve the 40% failure criteria. The following text calculates the maximum shot line height, Fig. 3, which can still achieve the 40% failure criteria (Eqs. 2 and 3).

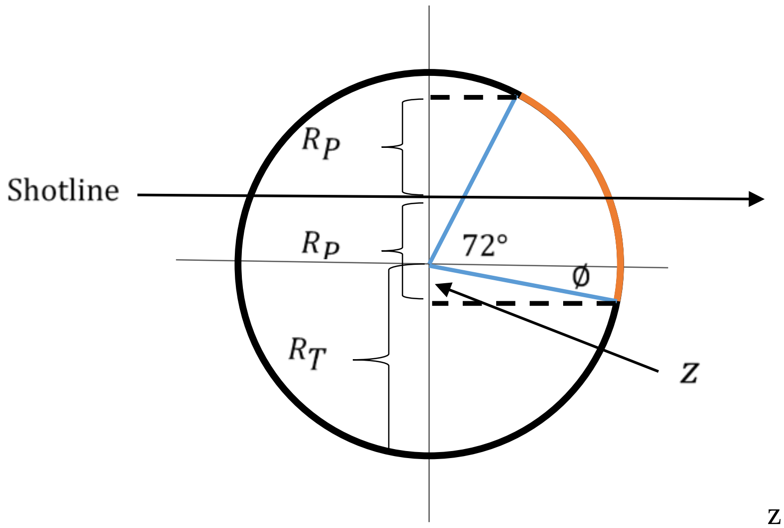

Fig. 3 Maximum shot line height

R_T = Tube Radius (0.5 inch)

R_p = Projectile Radius (0.25 inch)

Shot Line Height $= R_T + z - Rp$

The top angle can be defined as

$$\sin(72° - \emptyset) = \frac{2Rp - z}{R_T}. \tag{2}$$

Solving for z

$$0.5\sin(72° - \emptyset) = 0.5 - \mathrm{z}$$

$$z = 0.5 - 0.5(\sin(72° - \emptyset)).$$

The lower angle can be defined as

$$\sin \emptyset = \frac{z}{RT}. \tag{3}$$

Solving for z:

$$z = 0.5\sin\emptyset.$$

Setting both equations equal to each other, ∅ can be solved as

$$0.5\sin\emptyset = 0.5 - 0.5(\sin(72° - \emptyset))$$

$$\sin\emptyset + \sin(72° - \emptyset) = 1.$$

Based on the Fundamental Identities Equations,

$$\sin\alpha + \sin\beta = 2\sin(\tfrac{1}{2}(\alpha + \beta)) * \cos(\tfrac{1}{2}(\alpha - \beta))$$

$$2\sin\left(\tfrac{1}{2}(\emptyset + (72° - \emptyset))\right) * \cos(\tfrac{1}{2}(\emptyset - (72° - \emptyset)) = 1$$

$$2\sin 36° * \cos(\emptyset - 36°) = 1$$

$$\cos(\emptyset - 36°) = 0.851$$

Solving for ∅ yields 2 solutions:

$\emptyset = 4.283°,$	$\emptyset = 67.717°$
$\sin 4.283° = \frac{z}{RT}$	$\sin 67.717° = \frac{z}{RT}$
$z = 0.037$ inch	$z = 0.463$ inch
with $z = 0.037$ inch	with $z = 0.463$ inch
Shot line height = 0.287 inch	Shot line height = 0.713 inch

The vulnerable region in this example ranges from 0.096 to 0.287 inch in shot line height, resulting in a vulnerable height of 0.191 inch for the top region (Fig. 4). The second shot line height of 0.713 inch is the beginning of the vulnerable region in the lower portion of the tube. By symmetry, the lower region has the same vulnerable height as the top region.

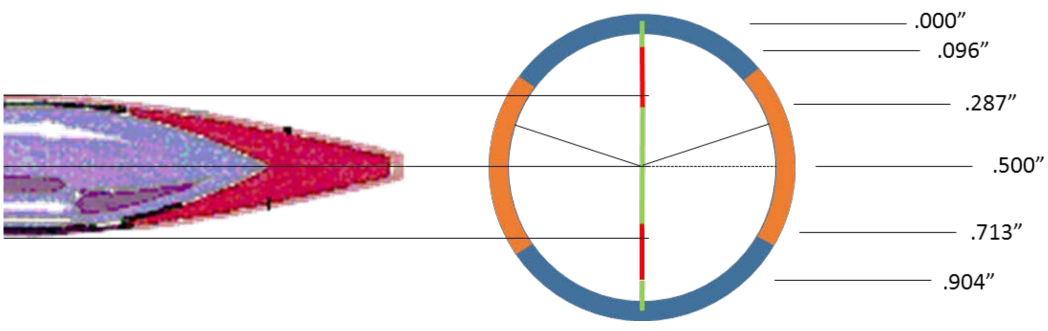

Fig. 4 Vulnerable regions for sample case

For this example, the vulnerable height is assessed as 0.382 inch and the presented height is 1.000 inch, resulting in a $p_{cd/h}$ value of 0.382 for the direct hit methodology. The effective size methodology begins to evaluate the component at a height that includes the threat's radius, so the presented height is increased to 1.50 inches. Since the failure criteria was not met until the threat was 0.095 inch below the top of the tube, there is no need to evaluate shot lines between the threat centerline and the top of the tube. In this example, the $p_{cd/h}$ value is 0.255 for the effective size methodology.

Results from the manual calculations and the CCM EM matched. Sample output for several tube diameters is provided in Figs. 5 and 6. The effects including threat hole growth for a 1.0-inch tube are shown in Figs. 7 and 8.

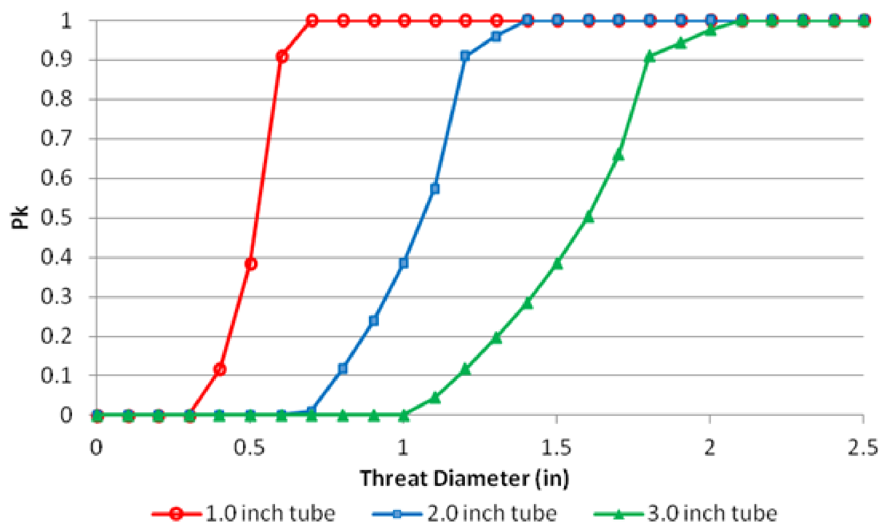

Fig. 5 Direct hit $p_{cd/h}$ vs. component diameter (0.4 failure criteria)

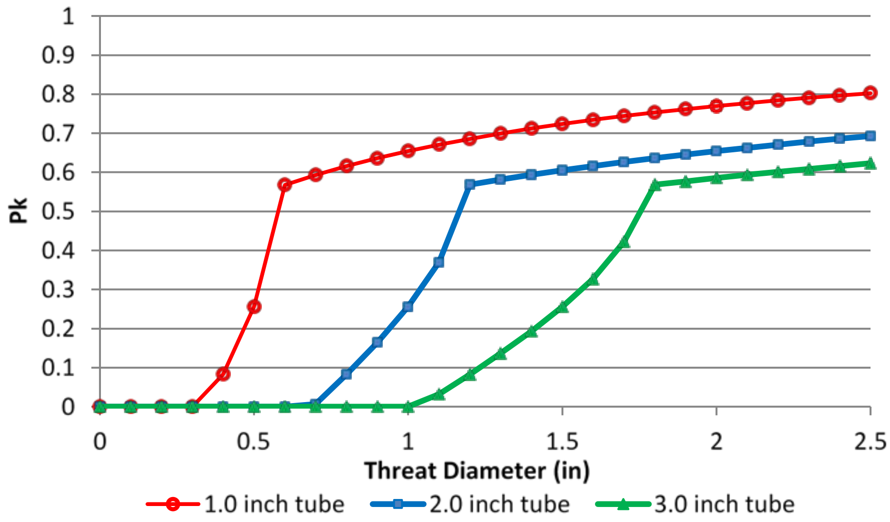

Fig. 6 Effective size $p_{cd/h}$ vs. component diameter (0.4 failure criteria)

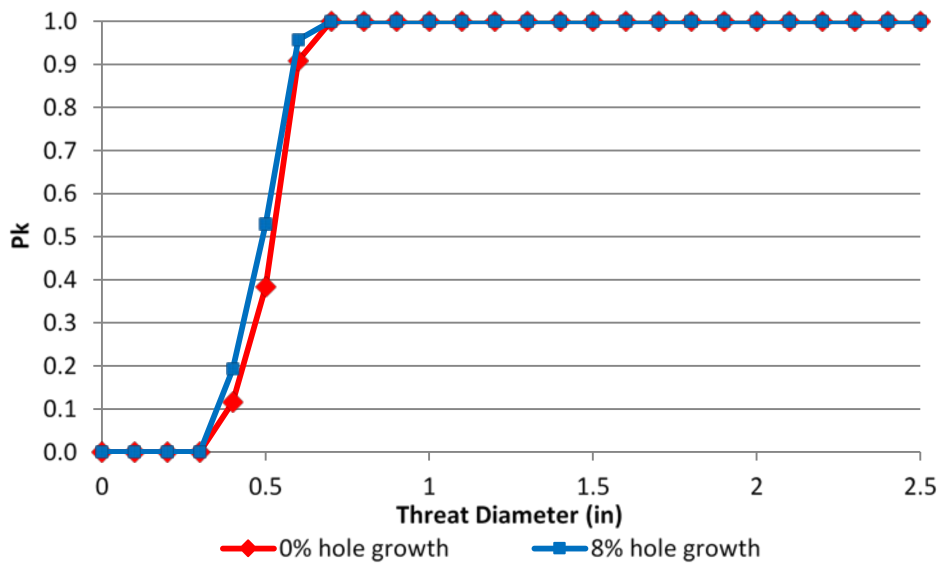

Fig. 7 Direct hit effects of threat hole growth (1.0-inch tube, 0.4 failure criteria)

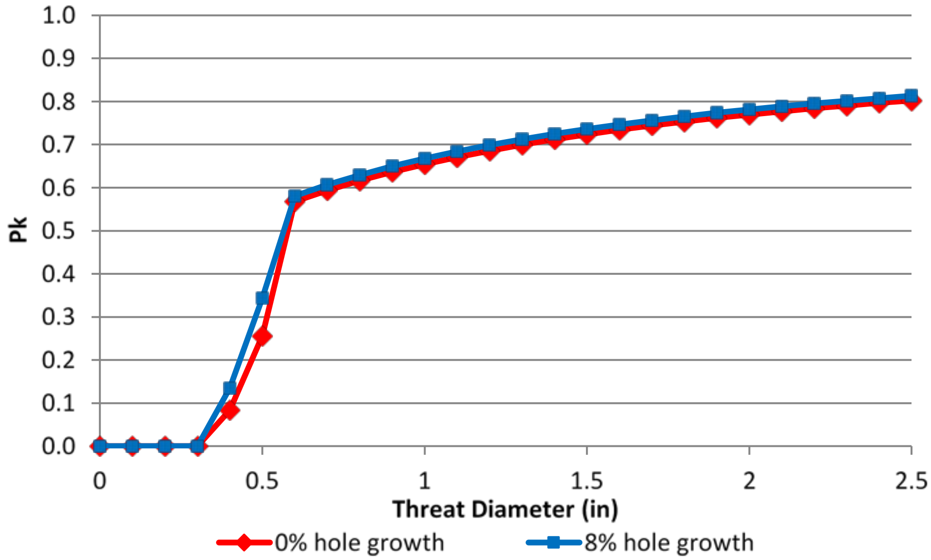

Fig. 8 **Effective size effects of threat hole growth (1.0-inch tube, 0.4 failure criteria)**

5. Using the Cylindrical_component EM in MUVES-S2

5.1 Effective Size Method

To use the effective size method to compute the $p_{cd/h}$ for a critical cylindrical component, the user must add a cylindrical_radius and a cylindrical_axis datum attribute to the BRL-CAD model of the component in the target description (.g file). The cylindrical_radius and cylindrical_axis datum attributes types are recognized by MUVES-S2 specifically for use with the cylindrical_component EM. Datum attributes are used to pass data about an object from BRL-CAD to MUVES. First, datum objects must be created for each critical cylindrical component in BRL-CAD. Each datum object contain points and vectors that define the position in space and dimensions of the cylindrical component. The cylindrical_radius and cylindrical_axis attributes are then set to the names of their respective datum objects. See Appendix C for more information on creating/editing datum objects and defining datum attributes in BRL-CAD.

The EM will use the cylindrical_radius datum attribute to obtain the radius of the cylinder. It will also use the cylindrical_axis datum to determine which shot lines are a near miss. For every threat shot line, the code computes the distance of closest approach between 2 line segments (the one represented by the cylindrical_axis datum and the one for the shot line) for each critical cylindrical component. If that distance is less than the sum of the cylinder radius plus the threat radius then the shot line is considered a near miss. The threat radius is computed using the (circularized) presented area of the threat accounting for yaw. The threat radius will also take into account hole growth if the user plays this option (see Section 6.6). A $p_{cd/h}$ will be computed for near-miss shot lines and for direct hit shot lines accounting for the effective size of both the threat and the cylinder.

5.2 Direct Hit Methodology

To use the direct hit method to compute the $p_{cd/h}$ for a critical cylindrical component, the user must only add the OUTSIDE_DIAM component property in the MUVES-S2 prop file to the component. The EM will use the OUTSIDE_DIAM component property to compute the radius of the cylinder. The threat radius is computed using the (circularized) presented area of the threat accounting for yaw. The threat radius will also take into account hole growth if the user plays this option. $P_{cd/h}$'s will only be computed for shot lines that directly hit the cylindrical component.

5.3 No Preference Method

If no_preference is the method chosen to compute cylindrical component $p_{cd/h}$'s, the direct hit method is employed if the OUTSIDE_DIAM property is set for the component. If the OUTSIDE_DIAM property is not set, the effective size method is employed if datums are present for the component. If both OUTSIDE_DIAM and datums are present, the direct hit method takes precedence over the effective size method. If neither OUTSIDE_DIAM nor datums are specified for the component, MUVES-S2 will terminate on the run and a fatal error will be reported. If a method is not chosen by the user, no_preference is the default.

5.4 Perforation

For the direct hit method and effective size method, MUVES-S2 will only compute $p_{cd/h}$'s for direct hit shot lines that completely perforate the critical cylindrical component.

For the effective size method, a $p_{cd/h}$ for the cylindrical component will only be computed for a near miss shot line if it perforates the adjacent component (component "near" the cylindrical component that the near-miss shot line passes through). However, on a near-miss shot line the code cannot determine whether complete perforation would have actually occurred with the threat and cylindrical component. Therefore, it is possible to get a $p_{cd/h} > 0$ on a near-miss shot line but get a $p_{cd/h} = 0$ on a direct hit shot with the same threat and cylindrical component under the same conditions (i.e., impact velocity, yaw).

5.5 Maximum Incidence Angle

As an option, the user can set the CYLINDRICAL_MAXIMUM_INCIDENCE component property to critical cylindrical components. The incidence angle is measured between the shot line direction vector and the cylindrical_axis datum vector (0^o = perpendicular, 90^o = tangential). This option allows one to only consider damage within a certain portion of the component length. It limits damage to shot lines that have an incidence angle less than the maximum value specified. This option can be used with either the direct hit or effective size method; however, in addition to setting the component property, the cylindrical_axis datum attribute must also be set in the BRL-CAD model of the component. If the component property is defined, but not the datum, the angle check is not performed.

5.6 Hole Growth

As an option, the user can set the CYLINDRICAL_HOLE_GROWTH component property to critical cylindrical components to grow the hole diameter created by the threat. This addresses the fact that a threat often leaves a slightly larger hole size than its actual diameter after penetration due to petaling effects of the component metal and other factors.

5.7 Intermediate Results File Information (.ir)

For shot lines that directly hit the critical cylindrical components, the code will create a cylindrical_component damage packet if the shot line perforated the cylindrical component and if the shotl ine has an incidence angle less than the maximum (if maximum is specified). When a damage packet is created, a $p_{cd/h}$ is computed for that shot line for that cylindrical component.

If a damage packet is created, the damage packet is output to the TD: (trace damage) line of the critical cylindrical component in the .ir file. The cylindrical_comp damage packet contains the name of the critical cylindrical component, the threat hole diameter (millimeter), and –1, which indicates that the shot line is a direct hit. The threat hole diameter is adjusted for the yaw of the projectile and hole growth if that option is played. In Fig. 9, a damage packet is created for a shot line that directly hit the critical cylindrical component "tube2", the effective threat diameter is 7.91562 mm, and the –1 indicates the shot line is a direct hit.

```
T: AAAP "tube2" Material="Steel_BHN_100"
 TG: entry=< -11.1125 101.6 -228.6 >  normal=< 1 -0 -0 >  dir=< -1 0 0 >  los=1.5875000  norm=1.5875000  obliq=0.0000000  wtlos=0.1587500  wtnorm=0.1587500
 TP: api7.62BZ_2000fps AAAP {  projweight=155  vel=1990.99  NCOR=1  prob_fire=0  yaw=8.30711  v50=-13.3329 }
 TP: {  prob_fire=0 }
 TD: cylindrical_comp=< tube2 7.91562 -1 >
```

Fig. 9 Direct hit damage packet in .ir file

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When the effective size method is used, the code will create a cylindrical_component damage packet for a near-miss shot line if it perforates the component adjacent to the cylindrical component and if the shot line has an incidence angle less than the maximum (if maximum is specified). When a near-miss damage packet is created, a $p_{cd/h}$ is computed for that shot line for that cylindrical component.

If a near-miss damage packet is created, it will show up on the TD: line for the adjacent component on the shot line. In the example shown in Fig. 10, the adjacent component is MUVES_target_gap. The cylindrical_comp damage packet contains the name of the cylindrical component, the effective threat diameter (millimeter), and the near-miss distance (millimeter).

```
T: AAAP "MUVES_target_gap" Material="Air"
 TG: entry=< 555.625 118.11 -228.6 >  normal=< 1 -0 0 >  dir=< -1 0 0 >  los=1111.2500000  norm=1111.2500000  obliq=0.0000000  wtlos=1111.2500000  wtnorm=1111.2500000
near_miss_list={{comp=tube2, dist=16.51}}
 TP: api7.62BZ_2000fps AAAP {  projweight=155  vel=1996.54  NCOR=1  prob_fire=0  yaw=15.6968  v50=217.078 }
 TD: cylindrical_comp=< tube2 7.87401 16.51 >
```

Fig. 10 Near-miss damage packet in .ir file

Additionally, all computed near-miss distances for the shot line and the respective cylindrical components were added to the TG: (trace geometry) line of the adjacent component in the .ir file. In the example shown in Fig. 10, the near-miss shot line enters adjacent component “MUVES_target_gap” and the near_miss_list produced shows a near-miss distance of 16.51 mm with cylindrical component “tube2”.

5.8 Log File Information (.log)

Two new environment variables were added for the cylindrical_component EM.

1) cylindrical_componentDebug: when set to any value, additional log messages are output by the cylindrical_component EM.

Figure 11 shows the names of the components (tube2, tube1) that are evaluated by the cylindrical_component EM and the computed cumulative probability of kill (pk) value for each component. The values r, R, and criteria are the threat radius and cylinder radius of the first damage packet evaluated. Criteria is the cylindrical kill criteria specified for the component.

```
cylindrical_component(tube2) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";149]: cylindrical_component.eval: entered phase 2
cylindrical_component(tube2) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";154]: Evaluating component tube2(4)
cylindrical_component(tube2) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";173]: Evaluating cylindrical_comp damage packet: pkt->thrclass = 13, thrclass = -1
cylindrical_component(tube2) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";193]: r=78.422, R=12.7, criteria=0.45, pk=0
cylindrical_component(tube2) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";223]: cumulative Pk = 1
cylindrical_component(tube1) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";149]: cylindrical_component.eval: entered phase 2
cylindrical_component(tube1) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";154]: Evaluating component tube1(3)
cylindrical_component(tube1) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";173]: Evaluating cylindrical_comp damage packet: pkt->thrclass = 13, thrclass = -1
cylindrical_component(tube1) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";193]: r=15.4165, R=12.7, criteria=0.45, pk=0
cylindrical_component(tube1) ["/muves/2.45/src/methods/s2/EM/s2EmCylindricalComponent.cpp";223]: cumulative Pk = 1
```

Fig. 11 Log data output by cylindrical_componentDebug

2) CylindricalCompDamageDebug – when set to any value, additional log messages are output by the cylindrical_comp damage function.

Figure 12 shows .log file output for a near-miss shot line using the effective size method. The log file output shows the shot line had a near miss with cylindrical component “tube2” (near-miss distance < max distance), but the shot line exceeded the max incidence angle of 45°. A near-miss damage packet was not created, and the analyst can verify why it was not created by using information output to the log file.

```
muverat: cylindrical_comp: Entered (entry=-27.2224 113.342 101.6, dir=0.00955772 -0.082605 -0.996537, cyl=tube1, comp=MUVES_target_gap)
muverat: cylindrical_comp: seen = 0, total = 0, next threat = AntiAirArmorPiercingProjectile
muverat: cylindrical_comp: near miss dist = 104.561 (max dist = 32.893)
muverat: cylindrical_comp: Entered (entry=-27.2224 113.342 101.6, dir=0.00955772 -0.082605 -0.996537, cyl=tube2, comp=MUVES_target_gap)
muverat: cylindrical_comp: seen = 0, total = 0, next threat = AntiAirArmorPiercingProjectile
muverat: cylindrical_comp: near miss dist = 25.6924 (max dist = 32.893)
muverat: cylindrical_comp: incidence angle = 85.23 (max = 45)
```

Fig. 12 Log data output by CylindricalCompDamageDebug

6. MUVES-S2 Inputs for the Cylindrical_component EM

This section describes the MUVES-S2 inputs and formats required for using the CCM EM. The inputs can vary depending on whether the analyst wants to compute the $p_{cd/h}$ based on the effective size method or the direct hit method. The inputs required for each method for each input file are specified in the following sections.

6.1 Session File

A cylinder_method modkey was added to MUVES-S2, which provides the user with 3 choices to compute the cylinder $p_{cd/h}$: 1) effective_size, 2) direct_hit, and 3) no_preference.

The user must specify the method for computing the cylindrical component $p_{cd/h}$. There are 2 ways to accomplish this:

- Using the MUVES GUI “method preferences” pull down menu, select “Method for computing cylindrical component $p_{cd/h}$”. Then select “effective_size”, “direct_hit”, or “no_preference”.

- Alternatively, in the session file, set the modkey, cylinder_method, to effective_size, direct_hit, or no_preference.

  Example: modkey cylinder_method effective_size

If no_preference is selected, the EM will check for inputs needed for the direct hit method first. If not found, effective size method will be used. If all the inputs for the effective size method are not specified, an error message is reported, and MUVES will terminate.

If the method preference or modkey is not specified, MUVES will default to no_preference.

6.2 Target Description File (.g)

If the user wants to use the direct hit method to compute the cylindrical component $p_{cd/h}$, there are no modifications to the .g file.

If the user wants to use the effective size method to compute the cylindrical component $p_{cd/h}$, the user must set the cylindrical_radius and the cylindrical_axis datum attributes for each critical cylindrical component in the target description (.g file). The cylindrical_radius and cylindrical_axis attributes are associated with datum objects. The cylindrical_radius and cylindrical_axis datum attributes are set to the datum's object name using the BRL-CAD editor, mged.

The following are example command lines to be used in mged:

```
attr set tube1.r cylindrical_radius tube1.radius

attr set tube1.r cylindrical_axis tube1.axis,
```

where tube1.radius and tube1.axis are the names of datum objects that each contain a point and direction vector that describe the radius and height of tube1.r, respectively.

See Appendix C to see how to create the cylindrical _radius and cylindrical_axis datum objects in mged.

6.3 Threat File (Initial)

The threat file does not require any modifications for use with the cylindrical_component EM.

However, the cylindrical_component EM has been tested to work with the following threat types:

AntiAirArmorPiercingProjectile (AP, API)

HighExplosiveIncendiary (HEI)

KineticEnergyPenetrator (KE)

ShapedChargeJet (SCJ)

ExplosivelyFormedPenetrator (EFP)

MassVelocityFragment (Thor/MVF fragments)

JTCGFragment (JTCG [Joint Technical Coordinating Group] fragments)

FATEPENFragment (FATEPEN [Fast Air Target Encounter PENetration]fragments)

For an HEI threat, a cylinder component $p_{cd/h}$ is computed for each fragment that interacts with the cylinder using the method and inputs specified by the user. The $p_{cd/h}$'s from each individual fragment are survivor summed to compute a final $p_{cd/h}$ for the cylinder.

6.4 Component Category Map (ccmap) file

A new **cylindrical** component category has been created as an option to the analyst. The analyst can decide whether to use the component category name in the des file, or use a qualifier instead. If the analyst uses the component category name, **cylindrical**, then in the des file the analyst should list the names of all the MUVES components to be evaluated by the cylindrical_component EM under the cylindrical category name in the ccmap file.

Example:

cylindrical

tube1

tube2

6.5 Damage Evaluation Selection (des) File

The name of the EM that invokes the CCM methodology is **cylindrical_component** and is specified in the des file.

Example 1:

Using the component category name, **cylinder:**

cylinder **cylindrical_component**

Example 2:

Alternatively, using a qualifier:

:[cylinder] **cylindrical_component**

6.6 Component Properties (prop) File

There are 4 component properties associated with the cylindrical_component EM; some are required, some are optional.

1) **CYLINDRICAL_KILL_CRITERIA** (required data for effective size and direct hit methods):

   CYLINDRICAL_KILL_CRITERIA is a required component property for each critical cylindrical component. The kill criteria is the fraction of circumference removed, which is the criterion for component damage. As an example, if 30% of the circumference of a control tube needs to be removed to cause it to fail, then the CYLINDRICAL_KILL_CRITERIA should be set to 0.3.

2) **OUTSIDE_DIAM** (required for direct hit method only):

   The outside diameter component property specifies the outside diameter of the cylindrical component in units millimeter. Note: If no_preference is selected as the cylinder_method and OUTSIDE_DIAM is defined for the component, the direct_hit methodology will be used even if the component has datums defined in the target description.

3) **CYLINDRICAL_MAXIMUM_INCIDENCE** (optional for effective size and direct hit methods)

   This property can only be used with a MUVES cylindrical component that has the cylindrical_axis datum attribute defined. The incidence angle is the angle between the shot line and the cylindrical axis datum vector, where 0° is a perpendicular shot and 90° is a tangential shot in the same direction of the cylinder's axis. If the incidence angle is greater than the CYLINDRICAL_MAXIMUM_INCIDENCE, no damage is produced. This option would be used to prevent the cylindrical component methodology from being used in a case where the damage from a 2-hole shot are spread too far apart along the length of the tube.

Examples:

```
tube2   MATERIAL                          Steel_BHN_300
        THICKNESS_FACTOR                  1.00
        OUTSIDE_DIAM                      12.7    # units mm
        CYLINDRICAL_KILL_CRITERIA          0.30
        CYLINDRICAL_MAX_INCIDENCE          45      # units degrees
```

4) **CYLINDRICAL_HOLE_GROWTH** (optional for effective size or direct hit method)

   This property allows the user to define the percentage of threat diameter increase due to penetration of thin-walled material. As an example, if the hole growth is 8%, CYLINDRICAL_HOLE_GROWTH would be set to 8, and the threat hole diameter would be multiplied by 1.08.

Example:

```
tube1   MATERIAL                          Steel_BHN_300
        THICKNESS_FACTOR                  1.00
        OUTSIDE_DIAM                      12.7     # units mm
        CYLINDRICAL_KILL_CRITERIA         0.30
        CYLINDRICAL_HOLE_GROWTH           8        # percent increase
```

6.7 Environ File

The cylindrical_component EM provides for 2 debug options that are set as environment variables. Diagnostics are output to the .log file.

In the session file, include this line:

env Cylindrical_ComponentDebug integer

to output diagnostics from the cylindrical_component EM

env CylindricalCompDamageDebug integer

to output diagnostics from the cylindrical_component damage function.

Alternatively, in the environment file, include this line and set this environment variable when using the MUVES GUI:

Cylindrical_ComponentDebug = integer

CylindricalCompDamageDebug = integer

7. Conclusions

SLAD developed the CCM EM during fiscal year 2015–2016 for computing the $p_{cd/h}$ for ballistic threats versus cylindrical components. As part of the development process, it has been rigorously tested and compared to independent results from manual calculations. The CCM EM will be integrated in MUVES-S2 version 2.45 as software change request (SCR) number 2115 and a corrective for HEI threats was integrated in MUVES-S2 version 2.46 as SCR 2202.

Two methods to calculate cylindrical component failure are included in this EM: direct hit and effective size. The direct hit methodology is consistent with other methodologies used by the US Army Research Laboratory's (ARL's) Aviation Analysis Team to analyze aircraft vulnerabilities. The direct hit EM method uses the current MUVES-S2 methodology of modeling a projectile's centerline path as a single nondimensional ray. When the ray impacts a component, MUVES-S2 calculates that component's vulnerability based on threat characteristics, penetration equations, and component vulnerability characterization data. By not including the projectile's diameter in the shot line calculations, this approach ignores the potential component vulnerability caused by a projectile grazing a component. The alternative to representing the threat as a single ray is to use a bundle of rays aligned around the projectile's diameter. This approach includes all possible impacts of the threat to components near or on the shot line. Since bundled rays are not part of the current standard MUVES-S2 analysis process the effective size methodology attempts to capture the near-miss vulnerabilities. Rather than including the threat's diameter through bundled rays, the effective size methodology grows the cylindrical component's diameter by the projectile's diameter. The cylindrical component's presented area is increased and therefore the component's vulnerability is analyzed on more shot lines, thus possibly increasing that component's contribution to the overall system vulnerability results. MUVES cannot determine whether perforation would have occurred with the threat and cylindrical component on a near-miss shot line. To partially compensate for this limitation, MUVES only computes a $p_{cd/h}$ on a near-miss shot line if it perforates the adjacent component.

ARL's Aviation Analysis Team prefers the direct hit methodology. It is consistent with how other components are being assessed in aircraft ballistic vulnerability analyses. The effective size methodology has merits; however, there are currently no means available to apply this methodology to the many other types of components within an aircraft.

8. References

1. Walther R. The cylindrical component Pcd/h method. SURVICE Engineering Company, Belcamp, MD; 2012 Jul. Report No.: SURVICE-TR-12-005.

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Appendix A. Cylindrical Component Probability of Component Damage Given a Hit ($p_{cd/h}$) Method Based upon Fraction of Circumference Removed

A complete mathematical derivation of the Cylindrical Component Probability of Component Damage Given a Hit ($P_{cd/h}$) Method based upon fraction of circumference removed is provided below.[1]

Notation:

D diameter of cylindrical tube

R $D/2$, radius of cylindrical tube

d effective diameter of projectile

r $d/2$, effective radius of projectile

C $2\pi r$, circumference of cylindrical tube

fc fraction of circumference removed, which is used as the criterion for component dysfunction

b impact parameter, minimum distance between center of cylinder and center of projectile

This methodology is based upon "The Cylindrical Component $P_{cd/h}$ Method" by Robert Walther.[2] The kill criterion of this methodology is based upon the fraction of the circumference removed by the impacting projectile. The methodology described here uses the same kill criterion but also provides documentation for developing a C++ program that automates the probability of component damage given a hit ($p_{cd/h}$) computation. At the same time, this description addresses a shortcoming of the Cylindrical Component $P_{cd/h}$ Method, which will be pointed out for the case when the projectile diameter is less than the cylinder diameter.

Taking into account the finite size of the projectile, the effective diameter of the cylinder is $D + d$, so it is important to recognize that the effective size of the cylindrical tube varies with the incoming projectile.

What we are considering here is what Walther calls the baseline case, where we are only concerned with geometry but not penetration. We derive $p_{cd/h}$ formulas based purely upon the geometry of the encounter without worrying about the penetration. Penetration is treated separately and will reduce the $p_{cd/h}$ values established here.

---

[1] Saucier R. Cylindrical component $p_{cd/h}$ method based upon fraction of circumference removed. Aberdeen Proving Ground (MD); 2014 Dec. ARL-SLAD white paper.

[2] Walther R. The cylindrical component Pcd/h method. SURVICE Engineering Company; 2012 Jul. Report No.: SURVICE-TR-12-005.

There are 2 distinct cases to consider: when the projectile diameter is greater than the cylinder diameter and when the projectile diameter is smaller than the cylinder diameter.

A.1 Case 1: Projectile Diameter Greater Than Cylinder Diameter: $d \geq D$

First consider the case where the fragment diameter is greater than the cylinder diameter. We have the situation shown in Fig. A-1.

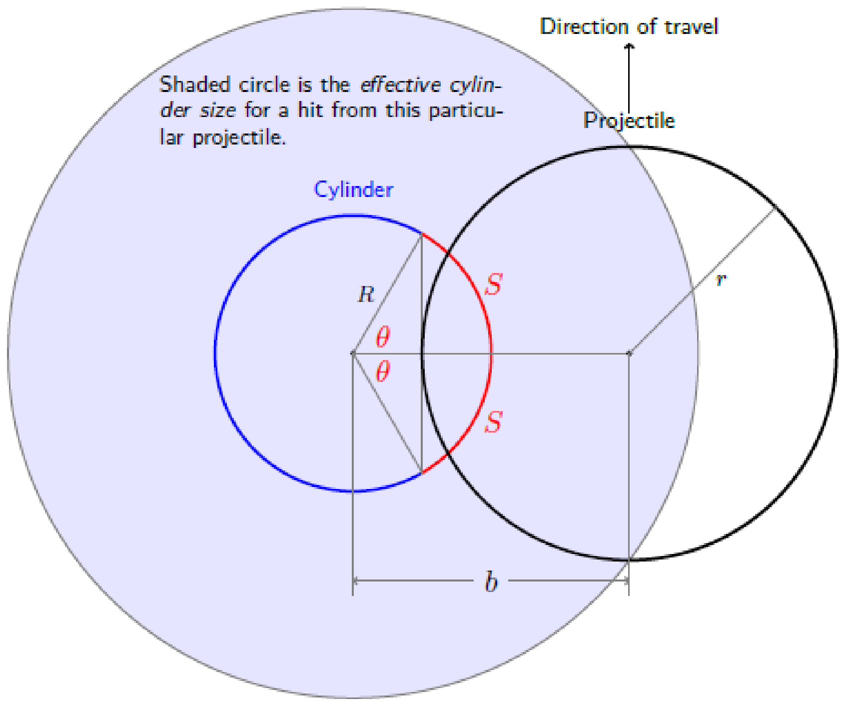

Fig. A-1 Diagram for computing $p_{cd/h}$ when the projectile diameter is greater than the cylinder diameter

Shown is an end-on view of the cylinder with the projectile traveling upward. When the center of the projectile is anywhere in the shaded region, it will result in a hit to the cylinder, and since $p_{cd/h}$ is the probability of damage given a hit, this is the effective size of the cylinder for this projectile. The arc length shown in red is the amount of the cylinder circumference that is removed from this encounter, assuming that the projectile penetrates through the cylinder (baseline case). The impact parameter b is the minimum distance between the center of the projectile and the center of the cylinder for this encounter.

The impact parameter b characterizes the impact conditions. If $0 \leq b \leq r - R$, then the projectile completely overlaps the cylinder, and if $b > r + R$, it will miss the cylinder. (Because of symmetry, it is only necessary to consider $b \geq 0$). When b lies between these 2 extremes, the fraction of the total circumference removed is

$$fc = \frac{2S}{C} = \frac{2\theta R}{2\pi R} = \frac{\theta}{\pi}. \tag{A-1}$$

From Fig. A-1 and using Eq. A-1,

$$b = R\ cos\theta + r = R\cos(\pi fc) + r \tag{A-2}$$

so fc is given by

$$fc = \begin{cases} 1\ if\ 0 \leq b \leq r - R \\ \frac{1}{\pi}\cos^{-1}\left(\frac{b-r}{R}\right) if\ r - R \leq b \leq r + R\ . \\ 0\ if\ r + R \leq b \end{cases} \tag{A-3}$$

Whether or not any particular impact constitutes a kill will depend upon the kill criterion, as specified by the value of fc, and which we label as fc_{kill}. At $b = 0$, the projectile would remove the entire circumference of the cylinder, which means the kill criterion will always be satisfied. Therefore,

$$b_{min} = 0, \tag{A-4}$$

regardless of the kill criterion. As b increases, we reach a point where

$$fc = \frac{1}{\pi}\cos^{-1}\left(b - \frac{r}{R}\right) = fc_{kill}\ . \tag{A-5}$$

This is guaranteed to occur since $fc = 1$ at $b = 0$ and $fc = 0$ at $b = R + r$. The maximum distance, beyond which the kill criterion is not satisfied, is given by

$$b_{max} = R\cos(\pi fc_{kill}) + r\ . \tag{A-6}$$

The range of b that results in a hit is

$$b_{hit} = R + r\ . \tag{A-7}$$

And since the probability of component damage given a random hit is $(b_{max} - b_{min})/b_{hit}$, we have

$$P_{cd/h} = \frac{R\cos(\pi fc_{kill}) + r}{R + r} \tag{A-8}$$

for the case where $d \geq D$.

A.2 Case 2: Projectile Diameter Less Than Cylinder Diameter: $\boldsymbol{d \leq D}$

The case where the projectile diameter is smaller than the cylinder diameter is slightly more complicated. In this case the minimum value of fc occurs when $b = 0$, and this impact is shown in Fig. A-2.

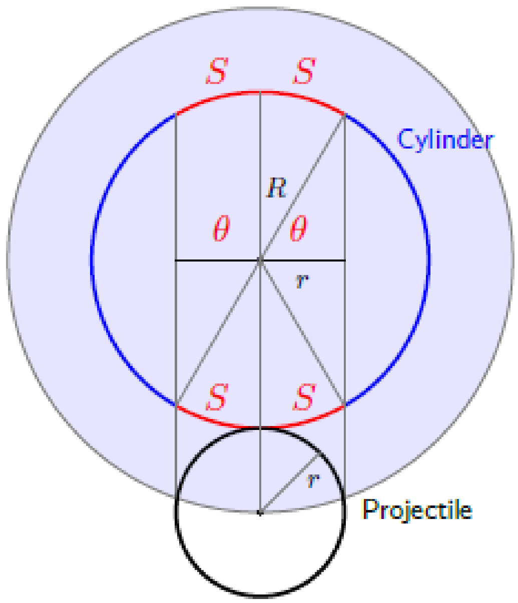

Fig. A-2 Diagram for computing $p_{cd/h}$ for the minimum 2-hole shot when the projectile diameter is less than the cylinder diameter

The total circumference removed in this case is $4S$, so the fraction of the total circumference removed is

$$fc_{min} = \frac{4S}{C} = \frac{4\left(\frac{\pi}{2}-\theta\right)R}{2\pi r} = 1 - \frac{2\theta}{\pi} \tag{A-9}$$

where the angle θ is given by

$$\cos\theta = \frac{r}{R}. \tag{A-10}$$

Therefore,

$$fc_{min} = 1 - \frac{2}{\pi}\cos^{-1}\left(\frac{r}{R}\right) \tag{A-11}$$

or

$$\frac{r}{R} = \cos\left(\frac{\pi}{2} - \frac{\pi}{2}fc_{min}\right) = \sin\left(\frac{\pi}{2}fc_{min}\right) \tag{A-12}$$

so that

$$fc_{min} = \frac{2}{\pi}\sin^{-1}\left(\frac{r}{R}\right). \tag{A-13}$$

This is the minimum fractional circumference that would be removed, and it may or may not satisfy the kill criterion. But notice that this is not the only place where a “2-hole” shot can occur. Figure A-3 depicts the maximum 2-hole shot when the impact parameter is $b = R - r$, the limit value for a 2-hole shot.*

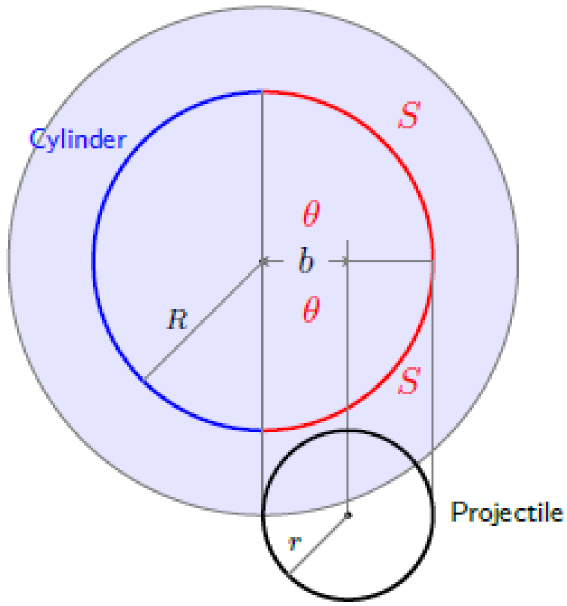

Fig. A-3 Diagram for computing $p_{cd/h}$ for the maxiumum 2-hole shot when the projectile diameter is less than the cylinder diameter

The fraction of the total circumference removed is

$$fc_{max} = \frac{2S}{C} = \frac{2\theta R}{2\pi R} = \frac{\theta}{\pi} \tag{A-14}$$

where the angle θ is given by

$$\cos\theta = \frac{R-2r}{R} = 1 - \frac{2r}{R}\,. \tag{A-15}$$

Therefore,

$$fc_{max} = \frac{1}{\pi}\cos^{-1}\left(1 - \frac{2r}{R}\right) \tag{A-16}$$

or

$$1 - \frac{2r}{R} = \cos(\pi fc_{max}) = 1 - 2sin^2\left(\frac{\pi}{2} fc_{max}\right). \tag{A-17}$$

The Cylindrical Component $P_{cd/h}$ Method only evaluates fc_{min}, and if this falls below the kill criterion, concludes that there are no 2-hole shots that satisfy the kill criterion. This is not necessarily true and we provide a counter-example in Fig. 3 of the main report.

* This value for the impact parameter also gives the maximum fc for a C-type shot.

Therefore

$$f c_{max} = \frac{2}{\pi} \sin^{-1}\left(\sqrt{\frac{r}{R}}\right). \tag{A-18}$$

The maximum 2-hole shot is also the maximum C-type shot. From this point on, as b increases from $R - r$ to $R + r$, we continue to get C-type shots but fc decreases from its maximum value fc_{max} to $fc = 0$. This geometry is shown in Fig. A-4, and we see that

$$b_{max} = R\cos(\pi f c_{kill}) + r, \tag{A-19}$$

which is the maximum value of the impact parameter that satisfies the kill criterion.

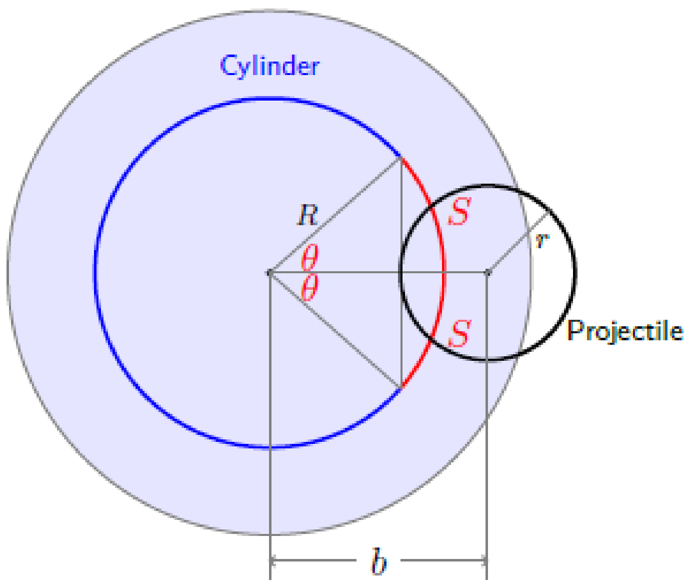

Fig. A-4 Diagram for computing $p_{cd/h}$ for a C-shot when the projectile diameter is less than the cylinder diameter

Now let's return to a typical 2-hole shot, as shown in Fig. A-5.

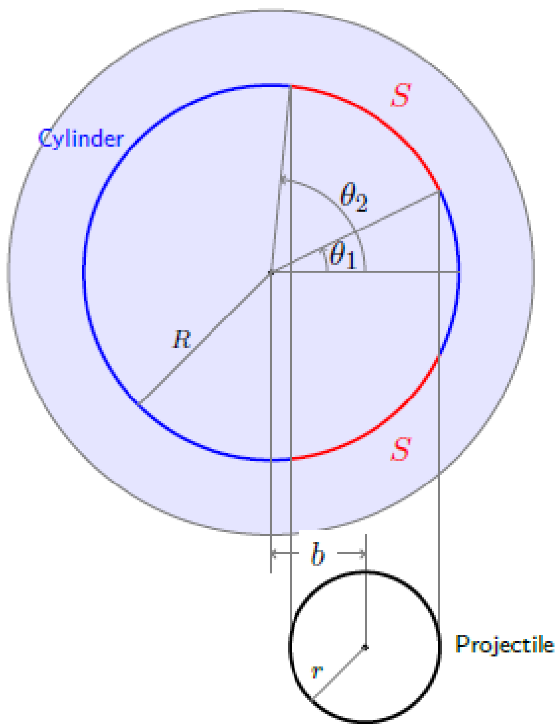

Fig. A-5 Diagram for computing $p_{cd/h}$ for the typical 2-hole shot when the projectile diameter is less than the cylinder diameter

The baseline case consists of computing the amount of the cylinder circumference that would be removed (shown in red) if the projectile passes completely through the cylinder.

The fraction of the total circumference removed is

$$fc = \frac{2S}{C} = \frac{2R(\theta_2 - \theta_1)}{2\pi R} = \frac{\theta_2 - \theta_1}{\pi} \tag{A-20}$$

where the angles from Fig. 5 are seen to be given by

$$\cos\theta_2 = \frac{b-r}{R} \, and \;\; \cos\theta_1 = \frac{b+r}{R}\,. \tag{A-21}$$

Therefore,

$$fc = \frac{1}{\pi}\left[\cos^{-1}\left(\frac{b-r}{R}\right) - \cos^{-1}\left(\frac{b+r}{R}\right)\right] \tag{A-22}$$

for $0 \leq b \leq R - r$.

This can be solved for b by making use of the trig functions in the complex plane. Let $z = \cos\theta$, so that $\theta = \cos^{-1} z$. Then

$$e^{i\theta} = \cos\theta + i\sin\theta = z + i\sqrt{1-z^2} \quad \text{(A-23)}$$

and

$$\cos^{-1} z = \theta = -i\ln\left(e^{i\theta}\right) = -i\ln\left(z + \sqrt{1-z^2}\right). \quad \text{(A-24)}$$

Making use of this in Eq. A-21, we have

$$\pi fc = -i\ln\left[\frac{b-r}{R} + i\sqrt{1-\left(\frac{b-r}{R}\right)^2}\right] + i\ln\left[\frac{b+r}{R} + i\sqrt{1-\left(\frac{b+r}{R}\right)^2}\right]$$

$$= -i\ln\left[\frac{\frac{b-r}{R} + i\sqrt{1-\left(\frac{b-r}{R}\right)^2}}{\frac{b+r}{R} + i\sqrt{1-\left(\frac{b+r}{R}\right)^2}}\right]$$

$$= -i\ln\left\{\left[\frac{b-r}{R} + i\sqrt{1-\left(\frac{b-r}{R}\right)^2}\right]\left[\frac{b+r}{R} - i\sqrt{1-\left(\frac{b+r}{R}\right)^2}\right]\right\}, \quad \text{(A-25)}$$

so that

$$e^{i\pi fc} = \cos(\pi fc) + i\sin(\pi fc) = \left[\frac{b-r}{R} + i\sqrt{1-\left(\frac{b-r}{R}\right)^2}\right]\left[\frac{b+r}{R} - i\sqrt{1-\left(\frac{b+r}{R}\right)^2}\right]. \quad \text{(A-26)}$$

Taking the real part of both sides gives

$$\cos(\pi fc) = \left(\frac{b-r}{R}\right)\left(\frac{b+r}{R}\right) + \sqrt{1-\left(\frac{b-r}{R}\right)^2}\sqrt{1-\left(\frac{b+r}{R}\right)^2}, \quad \text{(A-27)}$$

so that

$$\left[1-\left(\frac{b-r}{R}\right)^2\right]\left[1-\left(\frac{b+r}{R}\right)^2\right] = \left[\cos(\pi fc) - \left(\frac{b-r}{R}\right)\left(\frac{b+r}{R}\right)\right]^2. \quad \text{(A-28)}$$

Solving this for b, while making use of the trig identities

$$1-\cos\theta = 2\sin^2\frac{\theta}{2},\ 1+\cos\theta = 2\cos^2\frac{\theta}{2},\ \text{and } \sin\theta = 2\sin\frac{\theta}{2}\cos\frac{\theta}{2}, \quad \text{(A-29)}$$

we get

$$b = \cot\left(\frac{\pi}{2}fc\right)\sqrt{R^2\sin^2\left(\frac{\pi}{2}fc\right) - r^2} \quad \text{(A-30)}$$

where $fc_{min} \le fc \le fc_{max}$. Using Eqs. A-12 and A-17, it is easily checked that this formula gives $b = 0$ when $fc = fc_{min}$ and $b = R - r$ when $fc = fc_{max}$.

Putting all this together, we use the following procedure for computing the $p_{cd/h}$ when $d \le D$:

- If $fc_{max} < fc_{kill}$, then $P_{cd/h} = 0$.
- On the other hand, if $fc_{max} \geq fc_{kill}$, then we use Eq. A-19 to set

$$b_{max} = R\cos(\pi fc_{kill}) + r. \tag{A-31}$$

Next we calculate the value of b_{min}. First we test the value of fc_{min}, which occurs in the following when $b = 0$:

- If $fc_{min} \geq fc_{kill}$, then we set $b_{min} = 0$.
- On the other hand, if $fc_{min} < fc_{kill}$, then we use Eq. A-30 to set

$$b_{min} = \cot\left(\frac{\pi}{2} fc_{kill}\right)\sqrt{R^2 \sin^2\left(\frac{\pi}{2} fc_{kill}\right) - r^2}\ . \tag{A-32}$$

Then

$$P_{cd/h} = \frac{b_{max} - b_{min}}{R+r}\ . \tag{A-33}$$

Example 1 with $D = 1, d = 1.25, fc_{kill} = 0.35$

Since $r \leq R$, we apply Eq. A-7 and we get

$$P_{cd/h} = \frac{R\cos(\pi fc_{kill}) + r}{R+r} = 0.757. \tag{A-34}$$

Example 2 with $D = 1, d = 0.75, fc_{kill} = 0.35$

Since $r \leq R$, we need to apply Eq. A-33. First we compute

$$fc_{max} = \frac{2}{\pi}\sin^{-1}\left(\sqrt{\frac{r}{R}}\right) = 0.667 \tag{A-35}$$

and since this value exceeds $fc_{kill} = 0.35$, we know that $P_{cd/h} > 0$. Next we compute

$$b_{max} = R\cos(\pi fc_{kill}) + r = 0.602\ . \tag{A-36}$$

Also,

$$fc_{min} = \frac{2}{\pi}\sin^{-1}\left(\frac{r}{R}\right) = 0.540, \tag{A-37}$$

and since this also exceeds 0.35, we set $b_{min} = 0$ and therefore,

$$P_{cd/h} = \frac{(b_{max} - b_{min})}{R+r} = 0.688. \tag{A-38}$$

Example 3 with $D = 1, d = 0.5, fc_{kill} = 0.40$

Since $r \leq R$, we need to apply Eq. A-33. First we compute

$$fc_{max} = \frac{2}{\pi}\sin^{-1}\left(\sqrt{\frac{r}{R}}\right) = 0.5, \qquad \text{(A-39)}$$

and since this value exceeds $fc_{kill} = 0.40$, we know that $P_{cd/h} > 0$. Next we compute

$$b_{max} = R\cos(\pi fc_{kill}) + r = 0.405. \qquad \text{(A-40)}$$

Also,

$$fc_{min} = \frac{2}{\pi}\sin^{-1}\left(\frac{r}{R}\right) = 0.333, \qquad \text{(A-41)}$$

and since this falls below 0.40, we need to compute b_{min} using Eq. A-32

$$b_{min} = 0.213. \qquad \text{(A-42)}$$

Finally,

$$P_{cd/h} = \frac{(b_{max} - b_{min})}{R + r} = 0.256. \qquad \text{(A-43)}$$

A.3 Direct Hit Modification to Cylindrical Component $P_{cd/h}$ Method

Up to this point the $p_{cd/h}$ that we have been calculating is the probability of a kill, given a hit,

$$P_{cd/h} = \frac{P_k}{P_{hit}} \qquad \text{(A-44)}$$

where a hit is "metal on metal" contact, even if it is just a grazing shot. On the other hand, let P_{dhit} be the probability of a direct hit in which the center or the projectile hits somewhere on the tube. These would also be the shots that raytracing would flag as hits. Then

$$P_{cd/h} = \frac{P_k}{P_{dhit}}\frac{P_{dhit}}{P_{hit}}\,. \qquad \text{(A-45)}$$

Or, rearranging

$$\frac{P_k}{P_{dhit}} = P_{cd/h}\frac{P_{hit}}{P_{dhit}}\,. \qquad \text{(A-46)}$$

If D is the tube diameter and d is projectile diameter, then

$$\frac{P_{hit}}{P_{dhit}} = \frac{D+d}{D} = 1 + \frac{d}{D}\,. \qquad \text{(A-47)}$$

So that

$$\frac{P_k}{P_{dhit}} = P_{cd/h}\left(1 + \frac{d}{D}\right). \tag{A-48}$$

Since the probability can not be greater than 1, it should be

$$\frac{P_k}{P_{dhit}} = min\left[P_{cd/h}(1 + d/D), 1\right]. \tag{A-49}$$

A.4 Hole Enlargement

Another modification that could be made is to take into account that the hole in the target tends to be greater than the presented area of the projectile. The crater diameter when a projectile impacts semi-infinite metal is greater than the diameter of the projectile and is also a function of velocity. But even in the case of finite thickness metal, the hole diameter tends to be larger, and a value of 8%–10% was suggested. If we are conservative and use an 8% value, then we only need to make the replacement

$$d \Rightarrow 1.08d \tag{A-50}$$

in the equations for $P_{cd/h}$ and P_k/P_{dhit}.

A sample Python code for implementing all the key equations, and the modifications for direct hit and hole enlargement is shown in Fig. A-6.

```python
#!/usr/bin/env python
# baseline case for computing Pcd/h for cylindrical tubes based upon fractional circumference removed
# Ref: The Cylindrical Component Pcd/h Method by Robert Walther
# R. Saucier, Dec 2014 (Revised May 2016 for direct hit and hole enlargement)

import math

def impact_parameter( r, R, fc_kill ):
    a = 0.5 * math.pi * fc_kill
    s = math.sin( a );
    c = math.cos( a );
    return math.sqrt( ( R * s - r ) * ( R * s + r ) ) * c / s

def pk1( r, R, fc_kill ):   # returns pk, given r >= R
    return ( R * math.cos( math.pi * fc_kill ) + r ) / ( R + r )

def pk2( r, R, fc_kill ):   # returns pk, given r <= R
    PI_2 = 0.5 * math.pi
    RATIO  = r / R
    FC_MIN = math.asin( RATIO ) / PI_2
    FC_MAX = math.asin( math.sqrt( RATIO ) ) / PI_2;

    pk = 0.
    if ( FC_MAX < fc_kill ):
        return pk   # can't meet kill criterion

    b_max = R * math.cos( math.pi * fc_kill ) + r
    b_min = 0.
    if ( FC_MIN < fc_kill ):
        b_min = impact_parameter( r, R, fc_kill )
    b_hit = R + r
    pk = ( b_max - b_min ) / b_hit
    return pk

def pk( r, R, fc_kill ):
    if ( r >= R ): return pk1( r, R, fc_kill )
    else:          return pk2( r, R, fc_kill )

D       = input( 'Enter diameter of cylindrical tube:     ')
d       = input( 'Enter effective diameter of penetrator: ')
fc_kill = input( 'Enter kill criterion (between 0 and 1): ')

p = pk( 0.5 * d, 0.5 * D, fc_kill )
print( 'Assuming no increase in hole diameter:' )
print( 'Effective Diameter Method: Pcd/h = %.3f' % p )
print( 'Direct Hit Method:         Pcd/h = %.3f' % min( p * ( 1. + d / D ), 1. ) )

d *= 1.08;   # assuming 8% increase in hole diameter
p = pk( 0.5 * d, 0.5 * D, fc_kill )
print( 'Assuming 8% increase in hole diameter:' )
print( 'Effective Diameter Method: Pcd/h = %.3f' % p )
print( 'Direct Hit Method:         Pcd/h = %.3f' % min( p * ( 1. + d / D ), 1. ) )
```

Fig. A-6 Python program for computing baseline case $p_{cd/h}$

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Appendix B. MUVES-S2 Test Cases for Cylindrical_component Evaluation Module (EM)

B.1 Developmental Test 1

B.1.1 Test Definition and Purpose

For Test 1, a test case matrix was developed to test the Cylindrical Component Methodology Evaluation Model (CCM EM) for 3 threats against 3 targets. The threats were 7.62-mm armor piercing incendiary (API), 14.5-mm API, and 30-mm API. Each target consisted of 2 tubes and a plate contained in a simple box (i.e., the tubes represented internal target components). The tubes were MUVES components with the cylindrical_component EM assigned. The 3 targets differed only in the diameter size of the tubes, which were 0.5, 1.0, and 2.0 inches, respectively (Fig. B-1).

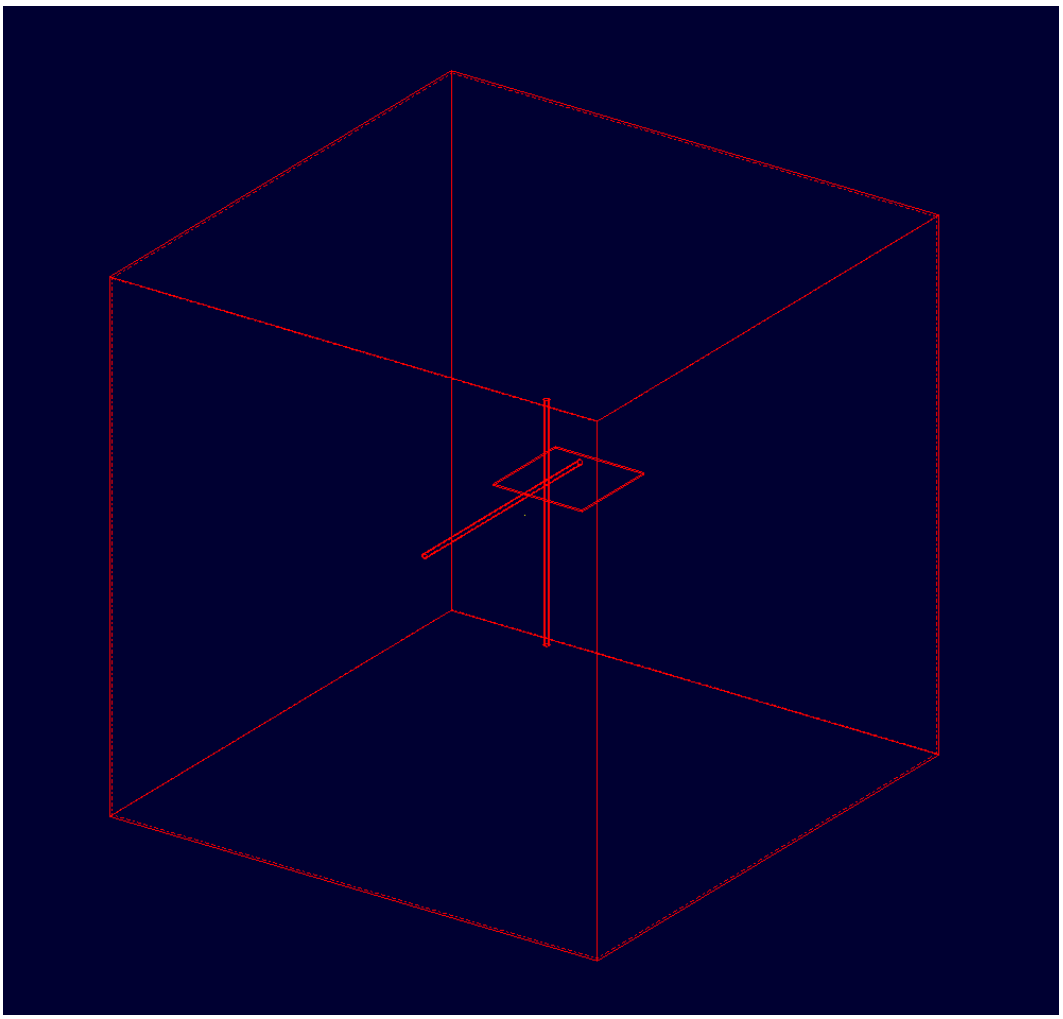


Fig. B-1 BRL-CAD test target for CCM EM: internal cylindrical components

Tube1 ran horizontally and tube2 ran vertically and intersected the plate. Each tube in each target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set for each tube for each analysis according to the diameter of the tubes in each target. The box surrounding the tubes and plate imparted yaw on the threat, which tested the MUVES calculation of effective threat hole diameter using the circularized presented area of the threat.

A view file was created with 4 shots:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube; does not enter hollow area of tube).
3. A “near-miss” shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
4. A “complete miss” shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criteria used were 0.30, 0.45, and 0.54 for the 0.5-, 1.0-, and 2.0-inch-diameter tubes, respectively. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file was created for each threat versus target combination for a total of 9 sessions. Four analyses were developed for each session file. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method
- no_preference
- cylinder_method modkey not set

The purpose of the test matrix was to exercise the CCM EM for various projectile diameter versus tube diameter combinations, various methods for computing the cylinder’s probability of component dysfunction given a hit ($p_{cd/h}$), various shot line conditions, and various MUVES settings. The test matrix has 36 test cases for the CCM EM.

The following session files are located on /n/king/muves/analysis/SCR2115 _Testing:

1. 7.62 mm_v_0.5in_tube
2. 7.62 mm_v_1.0in_tube

3. 7.62 mm_v_2.0in_tube
4. 14.5 mm_v_0.5in_tube
5. 14.5 mm_v_1.0in_tube
6. 14.5 mm_v_2.0in_tube
7. 30 mm_v_0.5in_tube
8. 30 mm_v_1.0in_tube
9. 30 mm_v_2.0in_tube

B.1.2 Test Results Verification

Manual calculations of cylinder component $p_{cd/h}$ were performed using the effective size and direct hit method. Manual calculations of cylinder component $p_{cd/h}$'s for the various test cases were compared to calculations generated by the CCM EM. Manual calculations and CCM EM calculations of $p_{cd/h}$'s are contained in Table B-1 for the 7.62-mm API threat, Table B-2 for the 14.5-mm API threat, and Table B-3 for the 30-mm API threat. Manual calculations and CCM EM calculations are in agreement.

Table B-1 A 7.62-mm API (0.31-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

SCR2115 Testing Results

Threat: 7.62mm API

Threat Diameter: 0.31 in

Cylindrical Kill Criteria: 0.30 (for 0.5-in tube), 0.45 (for 1.0-in tube), 0.54 (for 2.0-in tube)

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube.0.ir			7.62mm_v_1.0in_tube.0.ir			7.62mm_v_2.0in_tube.0.ir		
		Tube Diameter (in)							
	0.5			1.0			2.0		
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.917	0.746	0.746	7.916	0	0	7.914	0	0
cshot	7.917	0.746	0.746	7.917	0	0	7.917	0	0
near miss	7.874	0.746	0.746	7.874	0	0	7.874	0	0
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube.1.ir			7.62mm_v_1.0in_tube.1.ir			7.62mm_v_2.0in_tube.1.ir		
		Tube Diameter (in)							
	0.5			1.0			2.0		
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.917	1	1	7.916	0	0	7.914	0	0
cshot	7.917	1	1	7.917	0	0	7.917	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube.2.ir			7.62mm_v_1.0in_tube.2.ir			7.62mm_v_2.0in_tube.2.ir		
		Tube Diameter (in)							
	0.5			1.0			2.0		
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.917	1	1	7.916	0	0	7.914	0	0
cshot	7.917	1	1	7.917	0	0	7.917	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube.3.ir			7.62mm_v_1.0in_tube.3.ir			7.62mm_v_2.0in_tube.3.ir		
		Tube Diameter (in)							
	0.5			1.0			2.0		
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.917	1	1	7.916	0	0	7.914	0	0
c shot	7.917	1	1	7.917	0	0	7.917	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-2 A 14.5-mm API (0.59-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

Threat: 14.5mm API									
Threat Diameter: 0.59 in									
Cylindrical Kill Criteria: 0.30 (0.5-in tube), 0.45 (1.0-in tube), 0.54 (2.0in-tube)									

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)									
RUN	14.5mm_v_0.5in_tube.0.ir			14.5mm_v_1.0in_tube.0.ir			14.5mm_v_2.0in_tube.0.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	14.995	0.811	0.811	14.995	0.27	0.27	14.995	0	0
cshot	14.995	0.811	0.811	14.995	0.27	0.27	14.995	0	0
near miss	14.986	0.811	0.811	14.986	0.27	0.27	14.986	0	0
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)									
RUN	14.5mm_v_0.5in_tube.1.ir			14.5mm_v_1.0in_tube.1.ir			14.5mm_v_2.0in_tube.1.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
cshot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)									
RUN	14.5mm_v_0.5in_tube.2.ir			14.5mm_v_1.0in_tube.2.ir			14.5mm_v_2.0in_tube.2.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
cshot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)									
RUN	14.5mm_v_0.5in_tube.3.ir			14.5mm_v_1.0in_tube.3.ir			14.5mm_v_2.0in_tube.3.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
c shot	14.995	1	1	14.995	0.43	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-3 A 30-mm API (1.18-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

Threat: 30mm API									
Threat Diameter: 1.18 in									
Cylindrical Kill Criteria: 0.30 (0.5-in tube), 0.45 (1.0-in tube), 0.54 (2.0-in tube)									
Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)									
RUN	**30mm_v_0.5in_tube.0.ir**			**30mm_v_1.0in_tube.0.ir**			**30mm_v_2.0in_tube.0.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	29.980	0.877	0.877	29.980	0.613	0.613	29.980	0.036	0.036
cshot	29.980	0.877	0.877	29.980	0.613	0.613	29.980	0.036	0.036
near miss	29.972	0.877	0.877	29.972	0.613	0.613	29.972	0.035	0.035
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)									
RUN	**30mm_v_0.5in_tube.1.ir**			**30mm_v_1.0in_tube.1.ir**			**30mm_v_2.0in_tube.1.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	29.980	1	1	29.980	1	1	29.980	0.057	0.057
cshot	29.980	1	1	29.980	1	1	29.980	0.057	0.057
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: No preference (OUTER_DIAM specified; datums present)									
RUN	**30mm_v_0.5in_tube.2.ir**			**30mm_v_1.0in_tube.2.ir**			**30mm_v_2.0in_tube.2.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	29.980	1	1	29.980	1	1	29.980	0.056	0.057
cshot	29.980	1	1	29.980	1	1	29.980	0.056	0.057
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method:No selection (OUTER_DIAM specified; datums present)									
RUN	**30mm_v_0.5in_tube.3.ir**			**30mm_v_1.0in_tube.3.ir**			**30mm_v_2.0in_tube.3.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	29.980	1	1	29.980	1	1	29.980	0.056	0.057
c shot	29.980	1	1	29.980	1	1	29.980	0.056	0.057
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

B.2 Developmental Test 2

B.2.1 Test Definition and Purpose

The same test case matrix developed for Test 1 was used for Test 2 except the target geometry was modified. The exterior box around the tubes was removed from the 3 targets so the tubes would represent external components. Test 2's purpose is to ensure near-miss damage packets are created even if the shot line misses the cylindrical components when they are external to the target. The same threats were used: 7.62-mm API, 14.5-mm API, and 30-mm API. Each target consisted of 2 tubes and a plate. The 3 targets differed only in the diameter size of the tubes, which were 0.5, 1.0, and 2.0 inches, respectively (Fig. B-2).

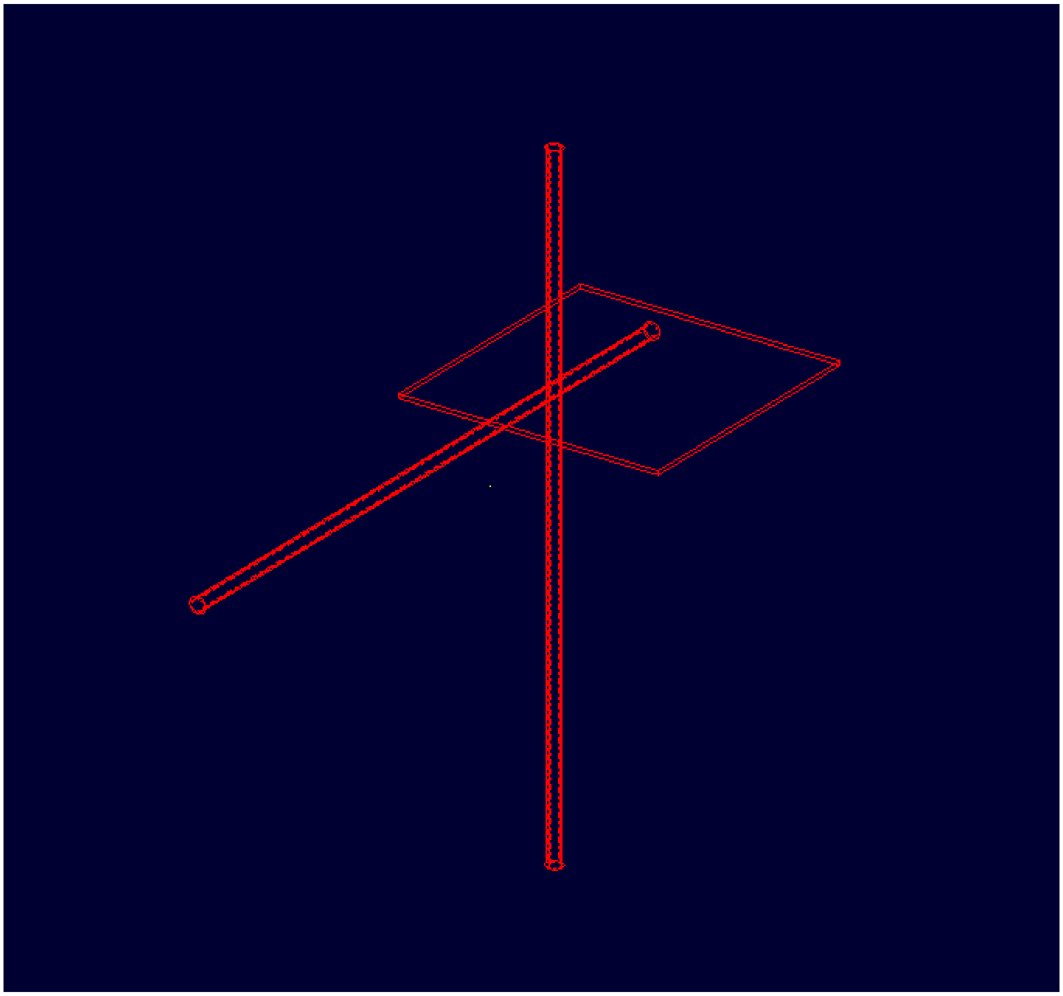


Fig. B-2 BRL-CAD test target for CCM EM: external cylindrical components

Tube1 ran horizontally and tube2 ran vertically and intersected the plate. Each tube in each target description had the BRL-CAD datum attributes, cylindrical_radius, and cylindrical_axis, created and set. The OUTER_DIAM component property was also set for each tube for each analysis according to the diameter of the tubes in each target.

The same view file used in Test 1 was used for Test 2. The 4 shot lines are as follows:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criteria used were 0.30, 0.45, and 0.54 for the 0.5-, 1.0-, and 2.0-inch-diameter tubes, respectively. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file was created for each threat versus target combination for a total of 9 sessions. Four analyses were developed for each session file. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method
- no_preference
- cylinder_method modkey not set

The purpose of the test matrix was to exercise the CCM EM for various projectile diameter versus tube diameter combinations, various methods for computing the cylinder's $p_{cd/h}$, various shot line conditions, and various MUVES settings. The test matrix is a set of 36 test cases for the CCM EM.

The following session files are located on /n/king/muves/analysis/SCR2115 _Testing:

1. 7.62mm_v_0.5in_tube_ext
2. 7.62mm_v_1.0in_tube_ext
3. 7.62mm_v_2.0in_tube_ext
4. 14.5mm_v_0.5in_tube_ext
5. 14.5mm_v_1.0in_tube_ext
6. 14.5mm_v_2.0in_tube_ext
7. 30mm_v_0.5in_tube_ext

8. 30mm_v_1.0in_tube_ext
9. 30mm_v_2.0in_tube_ext

B.2.2 Test Results Verification

Manual calculations of cylinder component $p_{cd/h}$ were performed using the effective size and direct hit method. Manual calculations of the cylinder component $p_{cd/h}$'s for the various test cases described in Section B2.1 of the main report were compared to calculations generated by the CCM EM. Manual calculations and CCM EM calculations of $p_{cd/h}$'s are contained in Table B-4 for the 7.62-mm API threat, Table B-5 for the 14.5-mm API threat, and Table B-6 for the 30-mm API threat. Manual calculations and CCM EM calculations are in agreement.

Fig. B-3 A 7.62-mm API (0.31-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter external tubes $p_{cd/h}$

Threat: 7.62mm API

Threat Diameter: 0.31 in

Cylindrical Kill Criteria: 0.30 (0.5-in external tube), 0.45 (1.0-inexternal tube), 0.54 (2.0-in external tube)

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)									
RUN	7.62mm_v_0.5in_tube_ext.0.ir			7.62mm_v_1.0in_tube_ext.0.ir			7.62mm_v_2.0in_tube_ext.0.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.874	0.746	0.746	7.874	0	0	7.874	0	0
cshot	7.874	0.746	0.746	7.874	0	0	7.874	0	0
near miss	7.874	0.746	0.746	7.874	0	0	7.874	0	0
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)									
RUN	7.62mm_v_0.5in_tube_ext.1.ir			7.62mm_v_1.0in_tube_ext.1.ir			7.62mm_v_2.0in_tube_ext.1.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.874	1	1	7.874	0	0	7.874	0	0
cshot	7.874	1	1	7.874	0	0	7.874	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)									
RUN	7.62mm_v_0.5in_tube_ext.2.ir			7.62mm_v_1.0in_tube_ext.2.ir			7.62mm_v_2.0in_tube_ext.2.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.874	1	1	7.874	0	0	7.874	0	0
cshot	7.874	1	1	7.874	0	0	7.874	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)									
RUN	7.62mm_v_0.5in_tube_ext.3.ir			7.62mm_v_1.0in_tube_ext.3.ir			7.62mm_v_2.0in_tube_ext.3.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	7.874	1	1	7.874	0	0	7.874	0	0
c shot	7.874	1	1	7.874	0	0	7.874	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-4 A 14.5-mm API (0.59-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter external tubes $p_{cd/h}$

Threat: 14.5mm API									
Threat Diameter: 0.59 in									
Cylindrical Kill Criteria: 0.30 (0.5-in external tube), 0.45 (1.0-in external tube), 0.54 (2.0-in external tube)									
Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_ext.0.ir**			**14.5mm_v_1.0in_tube_ext.0.ir**			**14.5mm_v_2.0in_tube_ext.0.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	14.995	0.811	0.811	14.995	0.27	0.27	14.995	0	0
cshot	14.995	0.811	0.811	14.995	0.27	0.27	14.995	0	0
near miss	14.986	0.811	0.811	14.986	0.27	0.27	14.986	0	0
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_ext.1.ir**			**14.5mm_v_1.0in_tube_ext.1.ir**			**14.5mm_v_2.0in_tube_ext.1.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
cshot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: No preference (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_ext.2.ir**			**14.5mm_v_1.0in_tube_ext.2.ir**			**14.5mm_v_2.0in_tube_ext.2.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
cshot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method:No selection (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_ext.3.ir**			**14.5mm_v_1.0in_tube_ext.3.ir**			**14.5mm_v_2.0in_tube_ext.3.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
c shot	14.995	1	1	14.995	0.429	0.43	14.995	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-5 A 30-mm API (1.18-inch diameter) vs. 0.5-, 1.0-, 2.0-inch-diameter external tubes $p_{cd/h}$

Threat: 30mm API
Threat Diameter: 1.18 in
Cylindrical Kill Criteria: 0.30 (0.5-in external tube), 0.45 (1.0-in external tube), 0.54 (2.0-in external tube)

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_ext.0.ir			30mm_v_1.0in_tube_ext.0.ir			30mm_v_2.0in_tube_ext.0.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	29.972	0.877	0.877	29.972	0.613	0.613	29.972	0.035	0.035
cshot	29.972	0.877	0.877	29.972	0.613	0.613	29.972	0.035	0.035
near miss	29.972	0.877	0.877	29.972	0.613	0.613	29.972	0.035	0.035
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_ext.1.ir			30mm_v_1.0in_tube_ext.1.ir			30mm_v_2.0in_tube_ext.1.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
cshot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_ext.2.ir			30mm_v_1.0in_tube_ext.2.ir			30mm_v_2.0in_tube_ext.2.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
cshot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_ext.3.ir			30mm_v_1.0in_tube_ext.3.ir			30mm_v_2.0in_tube_ext.3.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
c shot	29.972	1	1	29.972	1	1	29.972	0.056	0.056
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

B.3 Developmental Test 3

B.3.1 Test Definition and Purpose

The same test case matrix developed for Test 1 was used for Test 3 except CYLINDRICAL_HOLE_GROWTH was set to 8% for both tubes in the prop file. The purpose of Test 3 is to verify the CCM EM is calculating the $p_{cd/h}$ of the cylindrical component correctly when the cylindrical hole growth percentage is set in the prop file.

The same threats were used: 7.62-mm API, 14.5-mm API, and 30-mm API. Each target consisted of 2 tubes and a plate. The 3 targets differed only in the diameter size of the tubes, which were 0.5, 1.0, and 2.0 inches, respectively (Fig. B-1).

Tube1 ran horizontally and tube2 ran vertically and intersected the plate. Each tube in each target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set for each tube for each analysis according to the diameter of the tubes in the target.

A new view file was created for Test 3 to account for hole growth for near misses and complete misses. The following are the 4 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat including hole growth was taken into account).
4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat including hole growth was taken into account).

The cylindrical kill criteria used were 0.30, 0.45, and 0.54 for the 0.5-, 1.0-, and 2.0-inch-diameter tubes, respectively. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file was created for each threat versus target combination for a total of 9 sessions. Four analyses were developed for each session file. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method
- no_preference
- cylinder_method modkey not set

The following session files are located on /n/king/muves/analysis/SCR2115 _Testing:

1. 7.62mm_v_0.5in_tube_hg
2. 7.62mm_v_1.0in_tube_hg
3. 7.62mm_v_2.0in_tube_hg
4. 14.5mm_v_0.5in_tube_hg
5. 14.5mm_v_1.0in_tube_hg
6. 14.5mm_v_2.0in_tube_hg
7. 30mm_v_0.5in_tube_hg
8. 30mm_v_1.0in_tube_hg
9. 30mm_v_2.0in_tube_hg

B.3.2 Test Results Verification

Manual calculations of cylinder component $p_{cd/h}$ were performed using the effective size and direct hit methods and accounted for an 8% increase in threat hole size. Manual calculations of cylinder component $p_{cd/h}$'s for the various test cases described in Section B3.1 of the main report were compared to calculations generated by the CCM EM that accounted for an 8% increase in threat hole size. Manual calculations and CCM EM calculations of $p_{cd/h}$'s are contained in Table B-7 for the 7.62-mm API threat, Table B-8 for the 14.5-mm API threat, and Table B-9 for the 30-mm API threat. Manual calculations and CCM EM calculations are in agreement.

Table B-6 A 7.62-mm API with 8% hole growth (0.335-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

Threat: 7.62mm API

Threat Diameter: 0.31 in

Cylindrical Kill Criteria: 0.30 (0.5-in tube), 0.45 (1.0-in tube), 0.54 (2.0-in tube)

Hole Growth Percentage: 8

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube_hg.0.ir			7.62mm_v_1.0in_tube_hg.0.ir			7.62mm_v_2.0in_tube_hg.0.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	8.550	0.754	0.754	8.549	0	0	8.547	0	0
cshot	8.550	0.754	0.754	8.550	0	0	8.550	0	0
near miss	8.504	0.753	0.753	8.504	0	0	8.504	0	0
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube_hg.1.ir			7.62mm_v_1.0in_tube_hg.1.ir			7.62mm_v_2.0in_tube_hg.1.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	8.550	1	1	8.549	0	0	8.547	0	0
cshot	8.550	1	1	8.550	0	0	8.550	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube_hg.2.ir			7.62mm_v_1.0in_tube_hg.2.ir			7.62mm_v_2.0in_tube_hg.2.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	8.550	1	1	8.549	0	0	8.547	0	0
cshot	8.550	1	1	8.550	0	0	8.550	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)

RUN	7.62mm_v_0.5in_tube_hg.3.ir			7.62mm_v_1.0in_tube_hg.3.ir			7.62mm_v_2.0in_tube_hg.3.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	8.550	1	1	8.549	0	0	8.547	0	0
c shot	8.550	1	1	8.550	0	0	8.550	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-7 A 14.5-mm API with 8% hole growth (0.637-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

Threat: 14.5mm API									
Threat Diameter: 0.59 in									
Cylindrical Kill Criteria: 0.30 (0.5-in tube), 0.45 (1.0-in tube), 0.54 (2.0-in tube)									
Hole Growth Percentage: 8									
Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_hg.0.ir**			**14.5mm_v_1.0in_tube_hg.0.ir**			**14.5mm_v_2.0in_tube_hg.0.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	16.195	0.819	0.819	16.195	0.397	0.397	16.194	0	0
cshot	16.195	0.819	0.819	16.195	0.397	0.397	16.194	0	0
near miss	16.185	0.819	0.819	16.185	0.395	0.397	16.185	0	0
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_hg.1.ir**			**14.5mm_v_1.0in_tube_hg.1.ir**			**14.5mm_v_2.0in_tube_hg.1.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
cshot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method: No preference (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_hg.2.ir**			**14.5mm_v_1.0in_tube_hg.2.ir**			**14.5mm_v_2.0in_tube_hg.2.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
cshot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none
Cylinder Method:No selection (OUTER_DIAM specified; datums present)									
RUN	**14.5mm_v_0.5in_tube_hg.3.ir**			**14.5mm_v_1.0in_tube_hg.3.ir**			**14.5mm_v_2.0in_tube_hg.3.ir**		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
c shot	16.195	1	1	16.195	0.649	0.649	16.194	0	0
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Table B-8 A 30-mm API with 8% hole growth (0.335-inch diameter) vs. 0.5-, 1.0-, and 2.0-inch-diameter internal tubes $p_{cd/h}$

Threat: 30mm API

Threat Diameter: 1.18 in

Cylindrical Kill Criteria: 0.30 (0.5-in tube), 0.45 (1.0-in tube), 0.54 (2.0-in tube)

Hole Growth Percentage: 8

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_hg.0.ir			30mm_v_1.0in_tube_hg.0.ir			30mm_v_2.0in_tube_hg.0.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	32.378	0.884	0.884	32.378	0.629	0.629	32.378	0.100	0.1
cshot	32.379	0.884	0.884	32.378	0.629	0.629	32.378	0.100	0.1
near miss	32.370	0.884	0.884	32.370	0.629	0.629	32.370	0.100	0.1
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_hg.1.ir			30mm_v_1.0in_tube_hg.1.ir			30mm_v_2.0in_tube_hg.1.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	32.378	1	1	32.378	1	1	32.378	0.163	0.163
cshot	32.379	1	1	32.378	1	1	32.378	0.163	0.163
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method: No preference (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_hg.2.ir			30mm_v_1.0in_tube_hg.2.ir			30mm_v_2.0in_tube_hg.2.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	32.378	1	1	32.378	1	1	32.378	0.163	0.163
cshot	32.379	1	1	32.378	1	1	32.378	0.163	0.163
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)

RUN	30mm_v_0.5in_tube_hg.3.ir			30mm_v_1.0in_tube_hg.3.ir			30mm_v_2.0in_tube_hg.3.ir		
		Tube Diameter (in)							
		0.5			1.0			2.0	
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
two hole shot	32.378	1	1	32.378	1	1	32.378	0.163	0.163
c shot	32.379	1	1	32.378	1	1	32.378	0.163	0.163
near miss	none	none	none	none	none	none	none	none	none
total miss	none	none	none	none	none	none	none	none	none

B.4 Developmental Test 4

B.4.1 Test Definition and Purpose

The purpose of Test 4 is to verify that the CCM EM is using the correct diameter given the state of the projectile when it enters the cylindrical component. In this test case, the target material and line-of-sight thickness of the box surrounding the tubes was modified so that the projectile's jacket was stripped during penetration of the box. The core of the projectile entered the tube. The 14.5-mm API threat against a 1.0-inch tube was tested.

Each tube in the target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 1.0 inch (25.4 mm).

The view file for Test 4 had 4 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session with 4 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method
- no_preference
- cylinder_method modkey not set

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 14.5mm_v_1.0in_coreperf.

B.4.2 Test Results Verification

The intermediate results file from each analysis was used to verify that the core was impacting the tube and that the correct hole diameter was used for the CCM EM calculations. When the effective size method is used, the near-miss shot line had a slightly larger effective threat size than the direct hit shot lines (2-hole shot and C-shot). The reason the effective threat size is larger for the near-miss shot line is because ProjPen is computing yaw for the next component on the shot line. The yaw of the projectile is the yaw at the exit of the airgap space. Since the airgap is larger for the near miss than the direct hit shot lines, the projectile yaw is greater, resulting in a larger effective threat size. Manual calculations and CCM EM calculations of $p_{cd/h}$'s are contained in Table B-10 for the 14.5-mm API threat against the 1.0-inch tube for a core penetration. Manual calculations and CCM EM calculations are in agreement.

Table B-9 A 14.5-mm API vs. 1.0-inch tube $p_{cd/h}$ with core penetration

Threat: 14.5mm API			
Threat Diameter: 0.59 in		**Core diameter: 0.49 in**	
Cylindrical Kill Criteria: 0.45			
Core penetration into tube			

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	**14.5mm_v_1.0in_coreperf.0.ir**		
		1.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	12.616	0.109	0.109
cshot	12.617	0.109	0.109
near miss	14.986	0.27	0.27
total miss	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	**14.5mm_v_1.0in_coreperf.1.ir**		
		1.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	12.616	0.163	0.163
cshot	12.617	0.163	0.163
near miss	none	none	none
total miss	none	none	none

Table B-10 A 14.5-mm API vs. 1.0-inch tube $p_{cd/h}$ with core penetration (continued)

Cylinder Method: No preference (OUTER_DIAM specified; datums present)			
RUN	**14.5mm_v_1.0in_coreperf.2.ir**		
		1.0-in Tube Diameter	
shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	12.616	0.163	0.163
cshot	12.617	0.163	0.163
near miss	none	none	none
total miss	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)			
RUN	**14.5mm_v_1.0in_coreperf.3.ir**		
		1.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	12.616	0.163	0.163
c shot	12.617	0.163	0.163
near miss	none	none	none
total miss	none	none	none

B.5 Developmental Test 5

B.5.1 Test Definition and Purpose

The purpose of Test 5 is to verify that the CCM EM does not create a damage packet for the cylindrical component if the threat does not completely perforate the cylindrical component. The 7.62-mm API threat against a 2.0-inch tube was tested. The 7.62-mm API threat velocity was lowered to 1000 ft/s to reduce penetration. The 2.0-inch tube in the target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 2.0 inches (50.8 mm).

The view file for Test 5 had 4 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).

3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account)

The cylindrical kill criterion used was 0.54 for the 2.0-inch diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 4 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective size method
- direct hit method
- no_preference
- cylinder_method modkey not set

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 7.62-mm_v_2.0in_noperf.

B.5.2 Test Results Verification

The intermediate results file from each analysis was used to verify that 1) the threat did not completely penetrate the cylindrical component, 2) damage packets were not created for the cylindrical component, and 3) the $p_{cd/h}$ for the cylindrical component is zero. Results for the 4 analyses are given in Table B-11.

Table B-10 A 7.62-mm API vs. 2.0-inch tube $p_{cd/h}$; threat does not completely penetrate

Threat: 7.62mm API			
Threat Diameter: 0.31 in			
Cylindrical Kill Criteria: 0.54			
Threats do not completely penetrate cylindrical component			

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	**7.62mm_v_2.0in_noperf.0.ir**		
		2.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	none	none	none
cshot	none	none	none
near miss	7.874	0	0
total miss	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	**7.62mm_v_2.0in_noperf.1.ir**		
		2.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	none	none	none
cshot	none	none	none
near miss	none	none	none
total miss	none	none	none

Table B-11 A 7.62-mm API vs. 2.0-inch tube $p_{cd/h}$; threat does not completely penetrate (continued)

Cylinder Method: No preference (OUTER_DIAM specified; datums present)			
RUN	**7.62mm_v_2.0in_noperf.2.ir**		
		2.0-in Tube Diameter	
shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	none	none	none
cshot	none	none	none
near miss	none	none	none
total miss	none	none	none

Cylinder Method:No selection (OUTER_DIAM specified; datums present)			
RUN	**7.62mm_v_2.0in_noperf.3.ir**		
		2.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	none	none	none
c shot	none	none	none
near miss	none	none	none
total miss	none	none	none

For effective size method analysis, the direct hit shot lines (2-hole shot and C-shot) do not completely penetrate the tube, MUVES does not create a damage packet, and the $p_{cd/h}$ for the tube is equal to zero. However, for the near-miss shot line a damage packet is created, and the $p_{cd/h}$ for the tube turns out to be zero. This is a limitation of the effective_size method. On a near miss, MUVES cannot determine whether complete perforation would occur with the threat and cylindrical component. Therefore, it is possible to get a $p_{cd/h} > 0$ on a near-miss shot line but get a $p_{cd/h} = 0$ on a direct hit shot that does not completely perforate the cylindrical component for the same threat and cylindrical component. For the complete miss shot line, MUVES does not create a damage packet for the cylindrical component and the $p_{cd/h} = 0$.

For the direct hit method analysis, the direct hit shot lines (2-hole shot and C-shot) do not completely penetrate the tube, MUVES does not create a damage packet, and the $p_{cd/h}$ for the tube is equal to 0. Since the direct hit method does not account for near misses, MUVES does not create a damage packet, and the $p_{cd/h}$ for the tube is zero. For the complete miss shot line, MUVES does not create a damage packet for the tube and the $p_{cd/h} = 0$.

For the 2 analyses where the modkey is set to no_preference or is not set at all, the results are the same. Since datums and the OUTER_DIAM property are set, MUVES invokes the direct hit method since the OUTER_DIAM property overrides the datum properties. The direct hit shot lines (2-hole shot and cshot) do not completely penetrate the tube, MUVES does not create a damage packet, and the $p_{cd/h}$ for the tube is equal to zero. Since the direct hit method does not account for near misses, MUVES does not create a damage packet, and the $p_{cd/h}$ for the tube is zero. For the complete miss shot line, MUVES does not create a damage packet for the tube, and the $p_{cd/h} = 0$.

So for Test Case 5, CCM EM calculations and manual calculations match, and the CCM EM performs as expected. In the case of the near-miss shot line for the effective size method, the CCM EM performs as expected. The $p_{cd/h}$ will be calculated according to the effective size method; however, there is no way to verify the penetration of the threat with the cylindrical component, which is a limitation of the effective size method.

B.6 Developmental Test 6

B.6.1 Test Definition and Purpose

The purpose of Test 6 is to verify that the CCM EM does not create a damage packet for the cylindrical component if the incidence angle that the shot line creates with the cylindrical_axis datum vector exceeds the CYLINDRICAL_MAXIMUM _INCIDENCE component property if set. Test 6 verifies that MUVES does not create a damage packet and the $p_{cd/h}$ for the cylindrical component is zero.

The 14.5-mm API threat against a 2.0-inch tube was tested. The 2.0-inch tube in the target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 2.0 inches (50.8 mm). The CYLINDRICAL_MAXIMUM_INCIDENCE component property for the tube was set to 45°.

The view file for Test 6 had 3 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.54 for the 2.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 2 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method

The session file is located on /n/king/muves/analysis/SCR2115_Testing named max_incid_1.

B.6.2 Test Results Verification

The intermediate results file from each analysis was used to verify the incidence angle for each of the 3 shots on the cylindrical component, that damage packets were not created for the cylindrical component when the incidence angle exceeded the CYLINDRICAL_MAXIMUM_INCIDENCE, and the $p_{cd/h}$ for the cylindrical component is zero when the incidence angle exceeds the maximum. Results for the 2 analyses are given in Table B-12.

Table B-11 A 14.5-mm API vs. 2.0-inch tube $p_{cd/h}$; shot line incidence angles exceed maximum

Threat: 14.5mm API					
Threat Diameter: 0.59 in					
Cylindrical Kill Criteria: 0.54					
Cylindrical maximum incidence: 45 degrees					

Cylinder Method: Effective Size (OUTER_DIAM specified; datums present)

RUN	**max_incid_1.0.ir**			
			2.0-in Tube Diameter	
Shotline	**incidence angle**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	78.35	none	none	none
near miss	85.23	none	none	none

Cylinder Method: Direct Hit (OUTER_DIAM specified; datums present)

RUN	**max_incid.1.ir**			
			2.0-in Tube Diameter	
Shotline	**incidence angle**	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	78.35	none	none	none
near miss	none	none	none	none

For effective size method analysis, the 2-hole shot had an incidence angle of 78.35°, which exceeded the maximum set at 45°; the CCM EM did not create a damage packet, and the $p_{cd/h}$ for the tube was equal to zero. The C-shot (grazing shot) had an incidence angle of 25°. Since this did not exceed the maximum (45), a damage packet was created. The $p_{cd/h}$ was calculated using the effective size methodology and was equal to zero. The near-miss shot line had an incidence angle of 85.23°, which exceeded the maximum and the CCM EM did not create a damage packet; thus, the near-miss shot line had a $p_{cd/h}$ of zero.

For the direct hit method analysis, the 2-hole shot had an incidence angle of 78.35°, which exceeded the maximum set at 45°; the CCM EM did not create a damage packet, and the $p_{cd/h}$ for the tube was equal to zero. The C-shot had an incidence angle of 25°. Since this did not exceed the maximum (45), a damage packet was created. The $p_{cd/h}$ was calculated using the direct hit methodology and was equal to zero. Since the direct hit methodology does not account for near misses, the CCM EM did not create a damage packet for the near-miss shot line, thus, the $p_{cd/h}$ = 0.

So for Test Case 6, CCM EM calculations and manual calculations matched, and the CCM EM performs as expected.

B.7 Developmental Test 7

B.7.1 Test Definition and Purpose

The purpose of Test 7 is to verify that the CCM EM can be used with threat classes other than AntiAirArmorPiercingProjectiles. The CCM EM was tested with 6 MUVES sample threat files for a Shaped-Charge (SC) Munition, Kinetic Energy (KE) Penetrator, Explosively Formed Penetrator (EFP), Joint Technical Coordinating Group (JTCG) fragment, Fast Air Target Encounter PENetration (FATEPEN) fragment, and Thor fragment.

All threats were tested against a 1.0-inch tube. The 1.0-inch tube in the target description had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 1.0 inch (25.4 mm).

The view file for Test 7 had 4 shot lines, which were used to test all 6 threats. Depending on the threat size, the shot lines were direct hits, near misses, or complete misses.

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 2 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method

The session file is located on /n/king/muves/analysis/SCR2115_Testing named other_threats_v_1.0in_tube_ext.

B.7.2 Test Results Verification

The intermediate results file from each analysis was used to verify direct hit shots, near misses, and complete misses on the cylindrical component and to obtain effective threat diameter from damage packets that were created for the cylindrical components. Results for the 2 analyses are given in Table B-13.

Table B-12 Sample SC, KE, EFP, JTCG frag, FATEPEN frag, Thor Frag vs. 1.0-inch external tube $p_{cd/h}$

Threat: Sample Shaped-Charge (SC), Kinetic Energy (KE) Penetrator, Explosively Formed Penetrator (EFP), JTCG Frag, FATEPEN frag, Thor frag
Threat Diameter: varies
Cylindrical Kill Criteria: 0.45
Target: External 1.0-in tube

RUN	other_threats_v_1.0in_tube_ext.0.ir			other_threats_v_1.0in_tube_ext.1.ir		
	Effective Size			Direct Hit		
	Sample Shaped-Charge Munition (SC)					
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	73.018	0.782	0.782	73.018	1	1
direct hit	73.009	0.782	0.782	73.009	1	1
complete miss	none	none	none	none	none	none
complete miss	none	none	none	none	none	none
	Sample Kinetic Energy Penetrator (KE)					
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	69.319	0.774	0.774	69.319	1	1
direct hit	69.318	0.774	0.774	69.318	1	1
near miss	69.333	0.774	0.774	none	none	none
near miss	69.333	0.774	0.774	none	none	none
	Sample Explosively Formed Penetrator (EFP)					
shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	66.675	0.767	0.767	66.675	1	1
direct hit	66.675	0.767	0.767	66.675	1	1
near miss	66.675	0.767	0.767	none	none	none
near miss	66.675	0.767	0.767	none	none	none
	Sample JTCG Fragment					
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	32.079	0.627	0.627	32.079	1	1
direct hit	32.101	0.627	0.627	32.101	1	1
near miss	32.079	0.627	0.627	none	none	none
near miss	32.079	0.627	0.627	none	none	none
	Sample FATEPEN Fragment					
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	54.732	0.733	0.733	54.732	1	1
direct hit	54.732	0.733	0.733	54.732	1	1
complete miss	none	none	none	none	none	none
complete miss	none	none	none	none	none	none
	Sample Thor Fragment					
Shotline	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	2.762	0	0	2.762	0	0
direct hit	2.846	0	0	2.846	0	0
complete miss	none	none	none	none	none	none
complete miss	none	none	none	none	none	none

For effective size method analysis, damage packets were created for direct hit and near-miss shots. Damage packets were not created for complete miss shot lines. Effective threat diameters were obtained from the damage packets and the effective size methodology was used to calculate the cylinder component $p_{cd/h}$'s.

For the direct hit method analysis, damage packets were created for direct hit shot lines only. Effective threat diameters were obtained from the damage packets and the direct hit methodology was used to calculate the cylinder component $p_{cd/h}$'s.

CCM EM calculations and manual calculations match for Test 7, and the CCM EM performed as expected.

B.8 Developmental Test 8

B.8.1 Test Definition and Purpose

The purpose of Test 8 is to verify that the CCM EM can be used with the high-explosive incendiary (HEI) threat class that specifically fuzes prior to an internal cylinder component. The CCM EM was tested with a sample HEI threat file that was modified for the purposes of the test. The fuze_distance parameter was modified so the HEI detonated 5.5 inches before the internal cylinder; the nose_to_cg distance was set to 0.0. The fragment_initial_mass was increased by 100 g to make fragments large enough to achieve a near-miss fragment for testing purposes. Finally, all fragment zones except Zone4 Group2, and Zone4 Group3 frags were removed to reduce the number of manual $p_{cd/h}$ calculations. The internal cylinder was a 1.0-inch tube, which had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 1.0 inch (25.4 mm).

The view file for Test 8 had one shot line that set the detonation 5.5 inches directly in front of the tube.

The cylindrical kill criterion used was 0.45 for the 1.0-inch diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 2 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method

The session file is located on /n/king/muves/analysis/SCR2115_Testing named hei_fuze_prior_v_1.0in_tube.

B.8.2 Test Results Verification

The intermediate results (.ir) file from each analysis was used to verify the direct hit and near-miss fragments and their complete penetration through the cylinder. Results for the 2 analyses are given in Table B-14.

Table B-13 Sample HEI vs. 1.0-inch tube $p_{cd/h}$; HEI detonation before tube

Threat: Sample High Explosive Incendiary (HEI)							
Threat Diameter: fragment diameters vary							
Cylindrical Kill Criteria: 0.45							
Target: 1.0-in tube							
RUN	**hei_fuze_prior_v_1.0in_tube.0.ir**				**hei_fuze_prior_v_1.0in_tube.1.ir**		
	Effective Size Method				**Direct Hit Method**		
	High Explosive Incendiary						
frags	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**		**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
direct frag	156.844	0.882	0.882		156.844	1.000	1.000
near miss frag	30.081	0.614	0.614		none	none	none
direct hit frag	49.565	0.714	0.714		49.565	1.000	1.000
tube2 Pk		0.987	0.987	tube2 Pk		1.000	1.000

For the effective size method analysis, damage packets were created for the direct hit and near-miss fragments. Effective threat diameters were obtained from the damage packets and the effective size methodology was used to calculate the $p_{cd/h}$ for the cylinder from each fragment. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from each fragment were survivor summed.

For the direct hit method analysis, damage packets were created for direct hit fragments only. Effective threat diameters were obtained from the damage packets and the direct hit methodology was used to calculate the $p_{cd/h}$ for the cylinder from each fragment. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from each fragment were survivor summed.

CCM EM calculations and manual calculations match for Test 8, and the CCM EM performed as expected.

B.9 Developmental Test 9

B.9.1 Test Definition and Purpose

The purpose of Test 9 is to verify that the CCM EM can be used with the HEI threat class that specifically fuzes after passing through an internal cylinder component. The CCM EM was tested with a sample HEI threat file that was modified for the purposes of the test. The fuze_distance parameter was modified so the HEI detonated 2.5 inches after passing through the internal cylinder; the nose_to_cg distance was set to 0.0. The internal cylinder was a 1.0-inch tube that had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 1.0 inch (25.4 mm).

The view file for Test 9 had 3 shot lines:

1. A direct hit on tube2 (HEI projectile completely penetrated the tube).
2. A “near-miss” shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
3. A “complete miss” shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 2 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method

The session file is located on /n/king/muves/analysis/SCR2115_Testing named hei_fuze_after_v_1.0in_tube.

B.9.2 Test Results Verification

The intermediate results (.ir) file from each analysis was used to verify the complete penetration of the direct hit HEI projectile, direct hit fragments, and near-miss fragments. Results for the 2 analyses are given in Table B-15.

Table B-14 Sample HEI vs. 1.0-inch tube $p_{cd/h}$; HEI detonation after tube

Threat: Sample High Explosive Incediary (HEI)
Threat Diameter: fragment diameters vary
Cylindrical Kill Criteria: 0.45
Target: 1.0-in tube

RUN		hei_fuze_after_v_1.0in_tube.0.ir			hei_fuze_after_v_1.0in_tube.1.ir		
		Effective Size Method			Direct Hit Method		
Shotline	threat	effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
direct hit	direct hit HEI	31.750	0.625	0.625	31.750	1.000	1.000
	direct hit frag	11.775	0.060	0.060	11.775	0.087	0.087
	direct hit frag	11.971	0.071	0.071	11.971	0.105	0.105
	direct hit frag	8.546	0.000	0.000	8.546	0.000	0.000
	near miss frag	29.159	0.607	0.607	none	none	none
tube2 pk			0.871	0.871		1.000	1.000

Shotline	threat	Effective Size Method			Direct Hit Method		
		effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
near miss	near miss HEI	31.750	0.625	0.625	none	none	none
	direct hit frag	13.099	0.139	0.139	13.099	0.210	0.210
	direct hit frag	10.117	0.000	0.000	10.117	0.000	0.000
	direct hit frag	12.549	0.105	0.105	12.549	0.157	0.157
	direct hit frag	8.290	0.000	0.000	8.290	0.000	0.000
	direct hit frag	61.998	0.755	0.755	61.998	1.000	1.000
tube2 pk			0.929	0.929		1.000	1.000

Shotline	threat	Effective Size Method			Direct Hit Method		
		effective threat diam (mm)	CCM EM Calculation	Manual Calculation	effective threat diam (mm)	CCM EM Calculation	Manual Calculation
complete miss	direct hit frag	15.148	0.283	0.283	15.148	0.452	0.452
	direct hit frag	12.239	0.087	0.087	12.239	0.128	0.128
	direct hit frag	8.305	0.000	0.000	8.305	0.000	0.000
	direct hit frag	6.679	0.000	0.000	6.679	0.000	0.000
	direct hit frag	49.384	0.713	0.713	49.384	1.000	1.000
tube2 pk			0.812	0.812		1.000	1.000

For the effective size method analysis with a direct hit shot line, damage packets were created for the direct hit HEI projectile, direct hit fragments, and near-miss fragments.

SCR 2202 made a correction for the effective size method analysis with a near-miss shot line. A damage packet is now created for the HEI projectile. Damage packets were created for the direct hit fragments. There were no near-miss fragments. For the effective size method analysis with a complete miss shot line, a damage packet was not created for the HEI projectile since it completely missed the cylinder, but damage packets for the direct hit frags were created. There were no near-miss fragments. Effective threat diameters were obtained from the damage packets and the effective size methodology was used to calculate the $p_{cd/h}$ for the cylinder. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from the HEI projectile and each fragment were survivor summed.

For the direct hit method analysis with a direct hit shot line, damage packets were created for direct hit HEI projectile and direct hit fragments only. For the direct hit method analysis with a near-miss shot line, a damage packet was not created for the HEI projectile since it was a near miss. Damage packets were created for the direct hit fragments. For the direct hit method analysis with a complete miss shot line, damage packets were only created for the direct hit fragments. Effective threat diameters were obtained from the damage packets and the direct hit methodology was used to calculate the $p_{cd/h}$ for the cylinder from the HEI projectile and each fragment. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from the HEI projectile and each fragment were survivor summed.

CCM EM calculations and manual calculations match for Test 9, and the CCM EM performed as expected.

B.10 Developmental Test 10

B.10.1 Test Definition and Purpose

The purpose of Test 10 is to verify that the CCM EM can be used with the HEI threat class that specifically fuzes after passing through an external cylinder component. The CCM EM was tested with a sample HEI threat file that was modified for the purposes of the test. The fuze_distance parameter was modified so the HEI detonated 2 inches after passing through the external cylinder; the nose_to_cg distance was set to 0.0. The external cylinder was a 1.0-inch tube that had the BRL-CAD datum attributes, cylindrical_radius and cylindrical_axis, created and set. The OUTER_DIAM component property was also set to 1.0 inch (25.4 mm).

The view file for Test 10 had 3 shot lines:

1. A direct hit on tube2 (HEI projectile completely penetrated the tube).
2. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
3. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

One session file with 2 analyses was developed for this test case. Each analysis invoked a different modkey setting for cylinder_method:

- effective_size method
- direct_hit method

The session file is located on /n/king/muves/analysis/SCR2115_Testing named hei_fuzedist_v_1.0in_tube_ext.

B.10.2 Test Results Verification

The intermediate results (.ir) file from each analysis was used to verify the complete penetration of the direct hit HEI projectile, direct hit fragments, and near-miss fragments. Results for the 2 analyses are given in Table B-16.

Table B-15 Sample HEI vs. 1.0-inch external tube $p_{cd/h}$; HEI detonation after external cylinder

Threat: Sample High Explosive Incediary (HEI)							
Threat Diameter: fragment diameters vary							
Cylindrical Kill Criteria: 0.45							
Target: External 1.0-in tube							
RUN		**hei_fuzedist_v_1.0in_tube_ext.0.ir**			**hei_fuzedist_v_1.0in_tube_ext.1.ir**		
Shotline	**threat**	**Effective Size Method**			**Direct Hit Method**		
		effective threat diam (mm)	CCM EM Calculation	Manual Calculation	**effective threat diam (mm)**	CCM EM Calculation	Manual Calculation
direct hit	direct hit HEI	31.7501	0.6250	0.625	direct hit HEI	31.7501	1
	direct hit frag	11.9051	0.0670	0.067	direct hit frag	11.9051	0.099
	direct hit frag	14.9460	0.2660	0.266	direct hit frag	14.9460	0.423
	direct hit frag	8.7298	0.0000	0.000	direct hit frag	8.7298	0
tube2 pk			0.743	0.743		1	1
						s	
Shotline	**threat**	**Effective Size Method**			**Direct Hit Method**		
		effective threat diam (mm)	CCM EM Calculation	Manual Calculation	**effective threat diam (mm)**	CCM EM Calculation	Manual Calculation
near miss	near miss HEI	31.7500	0.6250	0.625	none	none	none
tube2 pk			0.625	0.625		0	0
Shotline	**threat**	**Effective Size Method**			**Direct Hit Method**		
		effective threat diam (mm)	CCM EM Calculation	Manual Calculation	**effective threat diam (mm)**	CCM EM Calculation	Manual Calculation
complete miss	none	none	none	none	none	none	none
tube2 pk			0	0		0	0

For the effective size method analysis with a direct hit shot line, damage packets were created for the direct hit HEI projectile and direct hit fragments. There were no near-miss fragments. For the effective size method with a near-miss shot line, a damage packet was created for the near-miss HEI projectile. There were no direct hit or near-miss fragments. For the effective size method with a complete miss shot line, no damage packets were created for the HEI projectile because it missed. There were no direct hit or near-miss fragments. Effective threat diameters were obtained from the damage packets and the effective size methodology was used to calculate the $p_{cd/h}$ for the cylinder from the HEI projectile and each fragment. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from the HEI projectile and each fragment were survivor summed.

For the direct hit method analysis with a direct hit shot line, damage packets were created for direct hit HEI projectile and direct hit fragments only. There were no near-miss fragments. For the direct hit method analysis with a near-miss shot line, a damage packet was not created for the near-miss HEI projectile. There were no direct hit or near-miss fragments. For the direct hit method analysis with a complete miss shot line, a damage packet was not created for the HEI projectile since it missed. There were no direct hit or near-miss fragments. Effective threat diameters were obtained from the damage packets and the direct hit methodology was used to calculate the $p_{cd/h}$ for the cylinder from the HEI projectile and each fragment. To calculate the final $p_{cd/h}$ for the cylinder, the $p_{cd/h}$'s from the HEI projectile and each fragment were survivor summed.

CCM EM calculations and manual calculations match for Test 10, and the CCM EM performed as expected.

B.11 Developmental Test 11

B.11.1 Test Definition and Purpose

The purpose of Test 11 is to verify that the CCM EM outputs an error message to the log file and terminates the analysis run when the effective size methodology is requested, but the cylinder radius or cylinder axis datum attributes do not exist in the target.

The CCM EM was tested with a 7.62-mm API threat file against the internal cylindrical components test target depicted in Fig. B-4. The cylinder targets did not have the cylinder radius and cylinder axis datum attributes defined. The cylinder_method requested in the session file was effective size.

```
muverat: LOG: Starting analysis session results/310.0.fr...
cylindrical_component.init: no cylindrical_radius datum found for tube2.
s2Init: cylindrical_component.init(tube2) failed because:
muverat: ERROR: Bad datum in BRL-CAD target model.
muverat: ERROR: Code interrupted by MuvesAnalysisTempFailError, caused by:
muverat: ERROR: Error on analysis session: 'results/310.0.fr'
```

Fig. B-4 Log file error message: no cylindrical radius datum found

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 310.

B.11.2 Test Results Verification

The log file from the analysis was used to verify error message was output.

B.12 Developmental Test 12

B.12.1 Test Definition and Purpose

The purpose of Test 12 is to verify that the CCM EM outputs an error message to the log file and terminates the analysis run when the direct hit methodology is requested, but the OUTER_DIAM component property is not set for cylinder component in the prop file.

The CCM EM was tested with a 14.5-mm API threat file against the internal cylindrical components test target depicted in Fig. B-5. The cylinder targets did not have the OUTER_DIAM component property defined in the prop file. The cylinder_method requested in the session file was direct hit.

```
muverat: LOG: Starting analysis session results/316.0.fr...
cylindrical_component.init: OUTSIDE_DIAM is not defined for tube2.
s2Init: cylindrical_component.init(tube2) failed because:
muverat: Required component properties not supplied.
muverat: ERROR: Code interrupted by MuvesAnalysisTempFailError, caused by:
muverat: ERROR: Error on analysis session: 'results/316.0.fr'
```

Fig. B-5 Log file error message: OUTSIDE_DIAM is not defined

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 316.

B.12.2 Test Results Verification

The log file from the analysis was used to verify error message was output.

B.13 Developmental Test 13

B.13.1 Test Definition and Purpose

The purpose of Test 13 is to verify that the CCM EM uses the direct hit method when 1) “no_preference” is selected as the cylinder_method, 2) the cylinders do not have datum attributes defined, and 3) the OUTER_DIAM component property for the cylinders are defined.

The CCM EM was tested with a 14.5-mm API threat file against the 1.0-inch internal cylindrical components test target depicted in Fig. B-3. The cylinder targets did not have the cylinder radius or cylinder axis datum attributes defined in the target .g file. The cylinder targets did have the OUTER_DIAM component property defined. The cylinder_method requested in the session file was “no_preference”.

The view file used contained 4 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).
4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 317.

B.13.2 Test Results Verification

The intermediate results (.ir) file from the analysis was used to verify the direct hit methodology was used. Results for the analysis are given in Table B-17. For the direct hit shot lines, the direct hit methodology was used to calculate the cylinder $p_{cd/h}$. Since the direct hit methodology does not account for near misses, the near-miss shot line produced no damage packets nor a $p_{cd/h}$ for the cylinder. There were no damage packets generated, nor $p_{cd/h}$’s calculated for the complete miss shot line as expected.

Table B-16 A 14.5-mm API vs. 1.0-inch tube $p_{cd/h}$; no preference cylinder method (OUTER_DIAM defined; datums not defined)

Threat: 14.5mm API							
Threat Diameter: 0.59 in							
Cylindrical Kill Criteria: 0.45							
Cylinder Method: No Preference (OUTER_DIAM specified; datums not present)							
RUN	**317.0.ir**						
		1.0-in Tube Diameter					
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**				
two hole shot	14.995	0.43	0.43				
cshot	14.995	0.43	0.43				
near miss	none	none	none				
complete miss	none	none	none				

B.14 Developmental Test 14

B.14.1 Test Definition and Purpose

The purpose of Test 14 is to verify that the CCM EM uses the effective size method when 1) “no_preference” is selected as the cylinder_method, 2) the cylinders have datum attributes defined, and 3) the OUTER_DIAM component property for the cylinders are not defined.

The CCM EM was tested with a 14.5-mm API threat file against the 1.0-in internal cylindrical components test target depicted in Fig. B-3. The cylinder targets had the cylinder radius and cylinder axis datum attributes defined in the target .g file. The cylinder components did not have the OUTER_DIAM component property defined. The cylinder_method requested in the session file was “no_preference”.

The view file used contained 4 shot lines:

1. A direct hit 2-hole shot on tube2 (a shot that intersects 2 walls of the tube and the hollow area inside the tube).
2. A direct hit grazing shot on tube2 (a shot that enters and exits outer wall of tube only; does not enter hollow area of tube).
3. A near-miss shot on tube2 (a shot that would impact the tube if the size of the threat was taken into account).

4. A complete miss shot on tube2 (a shot that would miss the tube if the size of the threat was taken into account).

The cylindrical kill criterion used was 0.45 for the 1.0-inch-diameter tube. The CYLINDRICAL_KILL_CRITERIA component property was set in the prop file accordingly.

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 320.

B.14.2 Test Results Verification

The intermediate results (.ir) file from the analysis was used to verify the effective size methodology was used. Results for the analysis are given in Table B-18. For the direct hit shot lines, the effective size methodology was used to calculate the cylinder $p_{cd/h}$. Since the effective size methodology does account for near misses, the near-miss shot line produced a damage packet and a $p_{cd/h}$ for the cylinder. There were no damage packets generated, nor $p_{cd/h}$'s calculated for the complete miss shot line as expected.

Table B-17 A 14.5-mm API vs. 1.0-inch tube $p_{cd/h}$; no preference cylinder method (datums defined; OUTER_DIAM not defined)

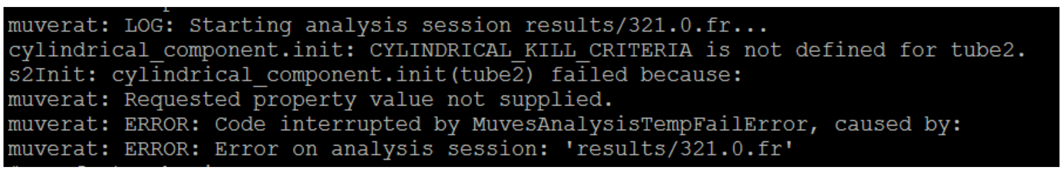
Threat: 14.5mm API			
Threat Diameter: 0.59 in			
Cylindrical Kill Criteria: 0.45			
Cylinder Method: No Preference (datums defined; OUTER_DIAM not defined)			
RUN	**320.0.ir**		
		1.0-in Tube Diameter	
Shotline	**effective threat diam (mm)**	CCM EM Calculation	**Manual Calculation**
two hole shot	14.986	0.27	0.27
cshot	14.986	0.27	0.27
near miss	14.986	0.27	0.27
complete miss	none	none	none

B.15 Developmental Test 15

B.15.1 Test Definition and Purpose

The purpose of Test 15 is to verify that the CCM EM outputs an error message to the log file and terminates the analysis run when the cylinder component methodology is requested, but the CYLINDRICAL_KILL_CRITERION component property is not set for cylinder component in the prop file.

The CCM EM was tested with a 14.5-mm API threat file against the internal cylindrical components test target depicted in Fig. B-6. The cylinder targets had the cylindrical_radius and cylindrical_axis datum attributes defined. The cylinder component had the OUTER_DIAM component property set in the prop file.



```
muverat: LOG: Starting analysis session results/321.0.fr...
cylindrical_component.init: CYLINDRICAL_KILL_CRITERIA is not defined for tube2.
s2Init: cylindrical_component.init(tube2) failed because:
muverat: Requested property value not supplied.
muverat: ERROR: Code interrupted by MuvesAnalysisTempFailError, caused by:
muverat: ERROR: Error on analysis session: 'results/321.0.fr'
```

Fig. B-6 Log file error message: CYLINDRICAL_KILL_CRITERIA is not defined

The cylinder_method requested in the session file was direct hit.

The session file is located on /n/king/muves/analysis/SCR2115_Testing named 321.

B.15.2 Test Results Verification

The log file from the analysis was used to verify error message was output.

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Appendix C. BRL-CAD Datum Attributes for Cylindrical_component Evaluation Module (EM)

Creating **cylindrical_radius** datum object for a cylinder component

To create a **cylindrical_radius** datum for cylinder region tube1.r in MGED:

Step 1. Set units

- **units mm**

Step 2. List out cylinder region tube1.r to get solid name

- **l tube1.r**

tube1.r: REGION id=1001 (air=0, los=100, GIFTmater=1) --
u tube1.s
- tube1.in

Step 3. List out tube1.s

- **l tube1.s**

  tube1.s: truncated general cone (TGC)
  V (-254, 0, 0)
  Top (254, 0, 0)
  H (508, 0, 0) mag=508
  H direction cosines=(0, 90, 90)
  H rotation angle=0, fallback angle=0
  A (0, 0, 12.7) mag=12.7
  B (0, 12.7, 0) mag=12.7
  C (0, 0, 12.7) mag=12.7
  D (0, 12.7, 0) mag=12.7
  AxB direction cosines=(180, 90, 90)
  AxB rotation angle=180, fallback angle=0

Step 3. Create the datum object "tube1.radius"

- **in tube1.radius**

  Enter solid type: **datum**
  Enter a datum type (point|line|plane): **line**
  Enter X,Y,Z for a point on the datum line: **–254 0 0** (Enter vertex of tube1.s)
  Enter X,Y,Z of the datum line direction vector: **0 0 12.7** (Enter A, B, C or D of tube1.s)

  Alternatively as a single command:

- **in tube1.radius datum line -254 0 0 0 0 12.7**

This creates a line datum named tube1.radius with a point at (–254, 0, 0) and a direction vector of <**0 0 12.7**>. Given units are in millimeters, this would yield a datum line describing a 12.7-mm radius. The point of the line is set to the vertex of the cylinder. The direction vector is pointing radially from the vertex, perpendicular to height vector.

Creating **cylindrical_axis** datum object for a cylinder component

To create a **cylindrical_axis** datum for cylinder region tube1.r in MGED:
Step 1: Set units

- **units mm**

Step 2: Create datum object "tube1.axis"

- **in tube1.axis**
  Enter solid type: **datum**
  Enter a datum type (point|line|plane): **line**
  Enter X,Y,Z for a point on the datum line: **–254 0 0** (Enter vertex of tube1.s)
  Enter X,Y,Z of the datum line direction vector: **508 0 0** (Enter H of tube1.s)

  Alternatively as a single command:
- **in tube1.axis datum line –254 0 0 508 0 0**

This creates a line datum named tube1.axis with a point at (–254, 0, 0) and a direction vector of <**508, 0, 0**>. Given units are in mm, this would yield a cylinder axis 508-mm in height. The point of the datum line is the vertex of the cylinder. The direction vector is pointing axially from the vertex, perpendicular to the radius vector.

Setting the datum attributes

- **attr set *tube1.r* cylindrical_radius *tube1.radius***
- **attr set *tube1.r* cylindrical_axis *tube1.axis***

This sets the cylindrical_radius datum attribute for region *tube1.r* to the newly created datum *tube1.radius*, and it sets the cylindrical_axis datum attribute for region *tube1.r* to the newly created datum *tube1.axis*.

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List of Symbols, Abbreviations, and Acronyms

AP	armor piercing
API	armor-piercing incendiary
ARL	US Army Research Laboratory
CCM	Cylindrical Component Methodology
Cr	circumference removed
EFP	explosively formed penetrator
EM	evaluation module
FATEPEN	Fast Air Target Encounter PENetration
HEI	high-explosive incendiary
JTCG	Joint Technical Coordinating Group
KE	kinetic energy
$p_{cd/h}$	probability of component damage given a hit
SCJ	shaped charge jet
SCR	software change request
SLAD	Survivability/Lethality Analysis Directorate
TD	trace damage
TG	trace geometry

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